AN ANALYSIS OF PERSONNEL PARACHUTES FOR USE BY MARINE CORPS FORCE RECONNAISSANCE UNITS

Robert Joseph McLaughlin

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AN ANALYSIS OF PERSONNEL PARACHUTES
FOR USE BY
MARINE CORPS FORCE RECONNAISSANCE UNITS

by

Robert Joseph McLaughlin

March 1977

Thesis Advisor: C. P. Gibfried

Approved for public release; distribution unlimited.

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) An Analysis of Personnel Parachutes for Use by Marine Corps Force Reconnaissance Units	5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; March 1977
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Robert Joseph McLaughlin	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940	12. REPORT DATE March 1977
	13. NUMBER OF PAGES 125
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California 93940	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

high glide parachutes
steerable parachutes
troop parachutes
free-fall parachutes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

There is an opportunity for the Marine Corps to adopt a free-fall parachute, especially for Force Reconnaissance units, where the emphasis is on achieving an assigned mission for the Force Commander. The subject of this thesis is to explore the field of free-fall and high-glide parachutes currently in use within the military establishment and the civilian community and to develop a model for selecting the most cost-effective free-fall parachute for use in the Marine Corps.

Approved for public release; distribution unlimited

An Analysis of Personnel Parachutes
for Use by
Marine Corps Force Reconnaissance Units

by

Robert Joseph McLaughlin
Major, United States Marine Corps
B. S., University of North Carolina, 1973

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
March 1977

ABSTRACT

There is an opportunity for the Marine Corps to adopt a free-fall parachute, especially for Force Reconnaissance units, where the emphasis is on achieving an assigned mission for the Force Commander. The subject of this thesis is to explore the field of free-fall and high-glide parachutes currently in use within the military establishment and the civilian community and to develop a model for selecting the most cost-effective free-fall parachute for use in the Marine Corps.

TABLE OF CONTENTS

LIST OF EQUATIONS

LIST OF TABLES

ACKNOWLEDGEMENTS

As the author of this dissertation, I would like to thank Lieutenant Colonel Carl Mundy Jr., United States Marine Corps, Naval War College, Newport, Rhode Island for his insight, practical approach, and faith; Major Richard G. Schwartz, United States Marine Corps, Marine Liaison Officer, United States Army Airborne, Communications Electronics Board, Fort Bragg, North Carolina for his help in preparation of this report; Colonel William R. Foley, United States Army, Director, Airborne Department, Quartermaster Corps, United States Army Quartermaster School, Fort Lee, Virginia for his insight and encouragement. Special acknowledgement is due to Captain James Capers, Jr., United States Marine Corps, Commanding Officer, 2d Force Reconnaissance Company and Master Gunnery Sergeant Franklin W. Hambrick, United States Marine Corps, LoftNCO, Air Delivery Platoon, Beach and Port Operations Company, Headquarters and Service Battalion, Force Troops/2d Force Service Support Group, Fleet Marine Force Atlantic, Camp Lejeune, North Carolina without whom completion of this thesis would have been impossible.

Superlative assistance, inspiration, motivational injections and comic relief are specifically acknowledged to the writer's thesis advisor without whose guidance this work would not have been completed successfully.

PREFACE

This thesis was written by a Marine Corps officer, with approximately eighteen years experience, on a topic largely parachute-oriented. As a result, it contains some acronyms, abbreviations, and other "jargon" which the non-parachutist reader may not understand. Every effort was made to keep these references to a minimum, and, where appropriate, to include parenthetical explanation via the use of a glossary. The glossary is designed to assist the reader in identifying the specific activities and terms referenced throughout this thesis. The reader already familiar with the mission of the Force Reconnaissance Company and parachuting techniques in general may desire to focus his attention on topics commencing with number VII, title, "Effectiveness Analysis." The reader inexperienced in parachuting will gain a more meaningful understanding of this research by reading all sections.

I. INTRODUCTION

A. GENERAL

The successful accomplishment of certain types of military airborne operations would be enhanced if the parachutists had the capability to glide and maneuver across relatively large distances while descending to their intended landing area. It would also be beneficial for them to have the capability of penetrating or moving against the prevailing wind. Many jumps by sport parachutists and military exhibition teams have demonstrated the feasibility of maneuverable, high-glide personnel parachutes. Within the last twenty years, parachutes have evolved from straight drag producing devices to those that glide, i.e., they have canopies that produce not only drag but also lift. The performance characteristics of the best known high-glide parachute designs are reviewed along with their possible application to military personnel airdrop operations. Although sport and exhibition jumps are being made as an everyday occurrence, many problems of a theoretical and practical nature remain to be solved for the successful application of high-glide parachutes to the more demanding requirements that might be necessary for military operations involving paratroopers.

When the tactical situation and mission requirements demand a clandestine penetration of selected areas, a preferred method may be the release of parachutists from

high altitudes using a free fall parachute technique to infiltrate personnel into an operational or objective area. Free fall parachute operations are generally characterized by flights over the objective area at altitudes not normally associated with parachute operations, and will normally be conducted in darkness or twilight to reduce the chance of enemy observation or detection. The parachutists are released at a point in space which is calculated to allow them to land within the objective area. Maneuverable parachutes, coupled with automatic opening devices, provide the detachment with the capability of all personnel opening at a predesignated altitude and landing together safely as a tactical unit prepared to execute its mission. Tactical military free fall parachuting should not be expected to produce pinpoint landing accuracy, but must be regarded as the means of entering a designated impact area within the objective area. The success of this type of drop, except under the most adverse circumstances, is assured regardless of the local weather condition or visibility. Free fall parachuting is advantageous under the following circumstances:

1. As a means of infiltration into hostile areas when low altitude penetration is not practical because of enemy detection or antiaircraft capability.

2. In mountainous terrain, where parachute operations using aircraft at low altitudes are prohibited, unsafe, or otherwise impractical.

3. When the impact area is limited in size.

4. When infiltration is to occur with other operations involving aircraft, or formations of aircraft, flying at high altitudes.

5. For insertion of small units or blind drop insertions.

6. When aircraft flying above hearing range will not be detected, e.g., in areas of operations where no radar or other sophisticated detection systems exist.

B. OBJECTIVE

The objective of this study is to discuss, determine and recommend the optimal maneuverable personnel parachute to be utilized by Marine Corps Force Reconnaissance Companies based on performance characteristics and related costs that would provide the commander the added flexibility and capability of performing forcible insertions of Marines into hostile areas by parachute.

II. BACKGROUND

A. FORCE RECONNAISSANCE MISSION

The primary mission as stated in Fleet Marine Force Manual 2-2 (FMFM2-2) [Ref. 1], of the Force Reconnaissance Company is, " . . . to conduct preassault and deep postassault reconnaissance in support of the landing force." FMFM2-2 also assigns a secondary mission to Force Reconnaissance units, " . . . provide initial terminal guidance for assault wave helicopters when parachuting is indicated as the insertion technique." From these missions, a rather difficult insertion requirement is derived: the tactical insertion of small reconnaissance teams (four to eight men) into enemy territory. How can these teams be clandestinely inserted into an assigned objective area, especially if these areas are several miles inland?

B. INSERTION METHODS

Available assets of helicopters, Amphibious Assault Ship (LPH) and Amphibious Transport Dock (LPD) in which a force reconnaissance unit may embark, together with newly realized exigencies of tactical situations confronting a commander, have given rise to the possibility that both free fall and static line parachute-qualified forces are not only possible but might provide a flexibility of valuable assets to meet satisfactorily various contingencies of modern warfare.

Presently, two basic means exist for Marines from the force reconnaissance unit to enter the objective area during an amphibious operation: (1) on or under the surface of the water, i.e., subsurface swimming, inflatible boat, small (IBS), and Navy swimmer delivery vehicle (SDV); (2) in the air above the objective area. In cases which the commander decides that surface or subsurface means are inappropriate and in cases in which the operating area is too far from the coast for amphibious insertion, only the second method of inserting a Marine reconnaissance team exists. The means presently available to Marine reconnaissance teams include landing by helicopter, rappelling from helicopters, and static line parachute jumping from fixed wing aircraft or helicopters.

While not specifically assigned as part of the mission of a Force Reconnaissance Company, following are some operations which involve free fall or static line parachute insertions:

1. In a deteriorating political situation requiring evacuation of American nationals paradrops of force reconnaissance Marines could quickly establish the "safe corridor" to the collection point.

2. In link-up with guerrilla forces, Marines from the Force Reconnaissance Company parachuted (either via free fall or static line) would eliminate the delay and problem of concealment of movement occasioned by moving over land.

3. Parachuted Force Reconnaissance Marines could establish an escape and evasion (E and E) net and using compact mobile techniques aid in inserting or extracting personnel.

4. Some objective areas are unsuitable for amphibious entry, whereas parachutists may land on hilly or flat terrain with small vegetation.

The strategic reach of the airborne force reconnaissance Marine is matched by no other since the force reconnaissance Marine has a tradition of being an elite Marine with a special expertise not available in other personnel within the Marine Corps.

C. HOSTILE ANTI-AIRCRAFT AND SMALL ARMS FIRE ENVIRONMENT

In a high or mid-intensity conflict, the anti-aircraft environment (with radar controlled guns and radar controlled surface-to-air missiles) insertion of reconnaissance teams by any aircraft means will be virtually impossible even with Electronic Counter Measures (ECM)--at least until many of the enemy anti-aircraft radars are destroyed. In a low-intensity conflict, however, the aircraft insertion means may be possible. Helicopters and low performance fixed wing aircraft may be utilized. Even in this environment, existing aircraft insertion means are hazardous. The present threat of air-ground missiles such as the SA-7 make standard insertion (static line) techniques difficult and in some cases impossible.

The helicopter is extremely vulnerable to SA-7 attack, as is any low performance aircraft below 10,000 feet. Anti-aircraft guns smaller than 50mm are also extremely effective against low performance aircraft below 10,000 feet. In general, the higher the airspeed, the more "survivable" the aircraft is under 10,000 feet. In fact, "burst" airspeeds in excess of 400 knots are considered to be essential to aircraft survival below 10,000 feet. Thus, static line parachute insertion, within the present state of the art, of reconnaissance teams, becomes extremely dangerous and sometimes impossible in an SA-7 environment because of the problems of "survivability" of insertion aircraft.

D. HIGH ALTITUDE LOW OPENING (HALO) TECHNIQUES

While static line parachute insertion, with current military parachutes, is not recommended above 500 to 1,000 feet because of long jumper exposure time under the canopy and possible increased team dispersion on landing, tactical insertion of small teams of parachutists is quite possible from any altitude between 2,500 feet and 30,000 feet by means of the HALO technique. With the HALO capability, four to eight parachutists could exit the aircraft together--at an altitude safely above the SA-7 range, free fall to a prescribed opening altitude together, and land together on the ground as a team, ready to carry out their mission, be it reconnaissance or terminal guidance. The insertion aircraft--whether capable of the 400+ knot "burst" airspeed

or not--is protected from SA-7 attack when HALO parachutists are dropped from altitudes above 10,000 feet.

HALO operations are primarily covert operations that require team integrity in a hostile environment. The opening altitude of the parachute should not be above 2,000 feet in order to permit team members to come to the ground as rapidly as possible.

E. ALTERNATE ENTRY REQUIREMENT

From the above discussion, it can be concluded that it would be advantageous to have a parachuting capability, in addition to static line parachutes, in the Marine Corps. This additional capability would allow the insertion of reconnaissance teams several miles or more inland during an amphibious operation in a low-intensity conflict with an SA-7 anti-aircraft environment.

There are certainly many circumstances when force reconnaissance personnel could be employed, either by free fall or static line parachute. While already possessing static line parachute capabilities, the addition of a free fall parachute capability provides greater flexibility to the commander, and, concomitantly, greater surprise to the enemy. This capability should not be overlooked. The Marine Corps, during this period of reduction and emphasis on quality, training, readiness, together with its area of operations involving proximity to foreign shores, and its compact, mobile organization of leadership, is uniquely suited to exploit this (free fall) capability.

III. MILITARY FREE FALL (MFF) VS. STATIC LINE PARACHUTING

A. RADAR SIGNATURE

Any aircraft inserting parachutists, whether static line (low altitude mission profile), HALO (high altitude mission profile)/MFF, is vulnerable to acquisition by enemy search radars. The best way to avoid detection is to fly very low, below the radar horizon, ascending to minimum parachuting altitude only for the short time necessary for the parachutists to exit the aircraft, and then returning to low level. Even such a "pop-up" delivery technique exposes that aircraft to radar acquisition during the 20+ seconds it is above the radar horizon. Thus, clandestine insertion of reconnaissance teams by parachute must be accomplished as part of a deception Electronic Countermeasure (ECM) plan. While the actual radar acquisition of parachutes using the static line/"pop-up" technique would be more difficult than radar acquisition of HALO or free fall parachutists, the mission profile of the insertion aircraft (low-high-low versus high at all times) would tend to imply parachutist insertion in the former case but not in the latter. Thus, so far as radar is concerned, both techniques have advantages and disadvantages. The commander in an amphibious operation would be in a better situation than he currently is, however, if he had the option of selecting the mission profile more suitable in his particular set of circumstances. At present,

he either utilizes the "pop-up" technique of inserting stat line parachutists or does not insert them at all.

B. GROUPING ADVANTAGES

In static line parachuting, utilizing the T-10,[1] MC1 or MC1-1[2] troop parachute, jumpers necessarily exist the aircraft individually because of potential static line/parachute/parachutist entanglement problems. A full second between parachutists is recommended to avoid such problems. This restriction means that reconnaissance team members are spread out along the flight path of the aircraft--the faster the aircraft speed, the greater the separation between the jumpers in a pass. Right from the start of a static line parachute insertion, the team members face the handicap of being separated. Since a tactical static line insertion would be conducted from as low an altitude as possible (perhaps 500 to 800 feet), insufficient time under the canopy is provided for the team members to maneuver together, even when using the manueverable MC1-1, and make up for this separation in the air. Thus, the jumpers will not land together on the ground as a team; they will be widely separated and will have to face the difficult and dangerous

---

[1]Throughout this study, when reference is made to the T-10 static line parachute, the reference includes the T-10A with improved harness and the T-10B with anti-inversion net.

[2]Throughout this study, the MC1-1 reference will include all models of the MC1-1 with modifications, e.g., MC1-1, MC1-1A, and MC1-1B. Also, the MC1-1 is synonymous and includes the Navy NSP 1, 2, and 3.

task of rendezvous in enemy territory before they can even begin their reconnaissance or guidance mission. This is, of course, especially hazardous at night, which is the only probable condition under which a tactical parachute insertion would be attempted. In free fall parachuting, however, no such exit separation problem exists. Since there are no static lines to foul with other static lines, other jumpers, the aircraft itself, etc., free fall parachutists may exit the aircraft together (from the ramp of a C-130, for example) or closely behind one another (if the exit opening of the aircraft restricts the number of jumpers that can fit at once). Thus, the team is together in the air from the beginning as they exit the aircraft. Free fall parachutists can be trained to fall together in the air as a relatively tight group (without physical contact between individual jumpers), to open together at the same altitude, to stay (or maneuver) together under the canopy, and to land together on the ground as a team. In this manner, the reconnaissance team can be intact at the start of an operation and can immediately proceed to conduct their mission.

C. HALO AND MFF

Although the teams are used interchangeably by all services, a distinction can be drawn between HALO parachuting and MFF parachuting.

Military Free Fall parachuting is a technique by which the parachutist jumps from a high altitude, is completely free from the aircraft, and falls for a predetermined time

or distance before canopy deployment. During free fall, body stabilizing techniques and necessary maneuvers are executed to aline the parachutist on his assigned heading. The parachute is activated manually by the ripcord, which is backed up by an automatic ripcord release set for a specified time interval or altitude. Use of a steerable canopy allows the parachutist to maneuver and land with great accuracy. Thus, MFF is not altitude dependent.

HALO, on the other hand, implies a non-static line jump from above 15,000 feet, and is, therefore, a special subcategory of MFF. The 15,000 foot distinction is the altitude at which oxygen is required by U. S. Air Force and U. S. Navy regulations for all crew members and passengers in unpressurized military aircraft. Thus, it can be seen that HALO jumpers would wear oxygen equipment, but MFF jumpers below 15,000 feet would not. The HALO vs. MFF distinction is only of military significance in regards to certain aircraft which will not support static line jumping but will support MFF. Appendix C discusses military free fall insertion aircraft, and also shows the aircraft that are compatible for static line parachuting. Thus, it is theoretically possible to speak in terms of MFF qualified parachutists who are not HALO qualified. Such parachutists would be able to jump a wider range of possible insertion aircraft than static line qualified parachutists and would, of course, capitalize on the potential grouping advantage of free fall operations mentioned above. However, an integral part of the instruction at the John F. Kennedy Institute for Military

Assistance (JFKIMA) Military Free Fall School at Fort Bra
North Carolina, is oxygen jumping; graduates of the MFF school are fully qualified HALO parachutists. No particular advantage is seen in training reconnaissance Marines in MFF parachuting without also devoting the small additional time to qualifying them in oxygen jumping (HALO).

D. CLANDESTINE INSERTION

In static line parachute insertions, the drop zone must be overflown at rather low altitude (500 to 800 feet). Enemy personnel near the drop zone would be alerted to the possible insertion of a team by this passage of the aircraft. In HALO and MFF operations, the aircraft can fly high enough to be unseen and unheard by personnel on the ground. Enemy personnel only a few hundred meters from the landing point of a free fall reconnaissance team need not have any indication of the team's insertion. Moreover, because of increased drift of the parachutist both in free fall and under the canopy, the track of the aircraft may be several thousand meters away from the drop zone. Thus, radar detection of the aircraft would not yield as small an area for the enemy to search for possible parachutist insertion for HALO or MFF operations as compared to static line operations.

IV. EQUIPMENT CONSIDERATIONS

Since 1963, when the Commandant of the Marine Corps issued an order curtailing free fall parachuting in the Marine Corps, great progress has been made in the development of equipment and techniques for both military and civilian free fall parachuting. Military static-line and free fall parachute techniques have been standardized in accordance with existing training manuals [Ref. 2].

All three sister services (Army, Air Force, and the Navy) conduct free fall parachuting in support of certain of their assigned missions and have standardized their equipment in support of their mission. As of this writing, the Army Communications and Electronics (ACE) Board, Ft. Bragg, North Carolina is testing and evaluating a new generation of free fall parachuting equipment and will more than likely continue to test and evaluate free fall parachutes as the state of the art continues to advance. Parachute test criteria was met by both the 35 foot nominal diameter parabolic circular canopy with the 7-TU modification (MC1 and MC1-1 parachutes) and by the Pioneer Para-Commander (MC3 parachute). The ACE Board has recommended adoption of the Para-Commander (MC3), with HALO configuration, for Special Forces free fall units [Ref. 3]. The present parachute used by Special Forces free fall "A" teams is the MC1 parachute, an earlier modification of the 35 foot nominal diameter parabolic circular canopy. The Air Force currently uses the

Para-Commander as the standard parachute for its free fall Combat Control Teams (CCT). The Navy currently uses the NSP-2 (which is the Navy designation of the 35 foot 7 gore "TU" parabolic circular canopy--i.e., the MC1-2 recommended by the ACE Board) as the standard parachute for Sea Air Land (SEAL) team free fall operations. While any of these three free fall parachutes (MC1, MC1-2, or MC3) could safely be adopted by the Marine Corps as the standard parachute for force reconnaissance free fall operations, consideration should also be given to existing free fall parachutes utilized by civilian sport parachute clubs.

The U. S. Navy has been conducting research investigations of several configurations of free fall parachutes with steerable canopy assemblies for potential use in a personnel, maneuverable, gliding parachute assembly at the U. S. Naval Aerospace Recovery Facility, El Centro, California, for a number of years [Ref. 4]. Their efforts centered around studying 11 configurations of circular and rectangular shaped parachute canopy assemblies with various types of orifices. In addition to these designs, the twin catenary keel parawing maneuverable personnel gliding parachute was tested on a limited basis. The rectangular shaped para-foil possesses a single chamber air-foil profile, resembling a conventional airplane wing.

The investigations and research conducted at El Centro were restricted to the determination of the performance of conventional solid cloth type parachute canopies with gores removed, orifices, and orifice-flap-combinations. These

parachutes depend on air being exhausted through the orifice to provide thrust and added glide velocity/forward speed.

In evaluating steerable parachutes, it is the canopy and the control means (slip risers or control lines) which are of significance. A steerable canopy may be packed into a number of different harness types for either static-line or free-fall jumps. Static-line parachute canopies are packed (stowed) in a deployment bag while free-fall parachute canopies are packed (stowed) in, and deployed from, a sleeve. The component parts utilized in conjunction with a particular canopy are considered to be of no consequence in evaluating the performance of the canopy. Once the canopy has opened, the other components have no bearing on the steerability and performance of that canopy.

V. ANALYTICAL APPROACH

The approach taken in this analysis, of various parachute canopy assemblies, is to determine the relative effectiveness of each parachute considered in relation to the objective of safely and accurately delivering a small team of men into a remote area within the area of interest of a Landing Force Commander. Once the alternatives have been evaluated in a relative sense, as to their performance capabilities and limitations, the various costs connected with each system will be studied and analyzed. With effectiveness and costs for each parachute identified, a basis for evaluating each system in terms of cost-effectiveness can be computed. Numerous models were developed and discussed before the model contained herein was determined acceptable for the approach which was finally felt to be appropriate. Several models were rejected because they contained insignificant variables while other models were rejected because they did not provide a good fit to data. It is recognized that if current restrictions are changed or if prescribed requirements for evaluating parachute performance are modified, the outcomes utilizing the model contained herein will be different and the recommendations found herein may not be appropriate.

VI. CONSTRAINTS

The following criteria are essential for military parachuting and are treated as constraints in this analysis. That is, all parachutes considered must meet these criteria; any of the alternatives described in Appendices A and B which do not meet these criteria are considered for comparative purposes only.

A. DESCENT RATE/LIFT CAPACITY

The descent rate will vary with a given canopy assembly depending on the suspended load. The maximum descent rate for a parachutist weighing 300 pounds with equipment is 25 feet per second and 20 feet per second with a 250 pound load [Ref. 5]. The constraints specified in Reference 10 will be utilized in the analysis of parachutes that the author feels has a military application and for which data is readily available.

B. STABILITY

The stability required for premeditated personnel parachute jumps is $\pm$ 10 degrees [Ref. 6]. This meaning is not further defined and since its format is not found universally, the requirement for "minimum rate of oscillation . . . to ensure that the landing attitude is not compromised" is substituted where necessary.

C. RELIABILITY

This is probably the most critical requirement for a personnel parachute. Consequently, it is placed at .999 and at .99 or above at a confidence level of .99 [Ref. 6]. Both figures require exhaustive and exacting testing, but because the latter is more statistically complete and the most recent, the figure, .99, will be used as the minimum acceptable for reliability purposes.

VII. EFFECTIVENESS ANALYSIS

The criteria identified as important for the purpose of measuring the effectiveness of parachute assembly systems are as follows.

A. EFFECTIVE DRAG COEFFICIENT

Also referred to as lift to drag ratio or glide rate, the effective drag coefficient is the ratio of the horizontal velocity of a parachute to its descent rate, both measured in still air. The author feels that this is extremely important in the discussion of parachute performance because it is the primary determinant of the accuracy with which a parachutist can maneuver himself into the drop zone. The horizontal velocity of a parachute is not always the same because it varies as a function of the descent rate (which in turn depends on the weight of the load). The effective drag coefficient, though, is constant for a given canopy, providing it is not being "braked" or "turned." Viewed algebraically, this relationship looks like this:

$$V_h = D \cdot R_d \tag{1}$$

R_d = rate of descent
V_h = horizontal velocity
D = drag coefficient

Horizontal velocity equals the product of the rate of descent and the effective drag coefficient. A parachute that floats straight down relative to the air, with no horizontal movement would have an effective drag coefficient of zero. On

the other hand, an effective drag coefficient greater than one indicates that the parachute moves faster laterally than it does vertically, even in still air. Clearly, a parachute with a high effective drag coefficient is better for a parachutist who exits an aircraft far from his target and by properly manipulating the canopy, can glide towards his target.

B. TURNING RATE

The other component of parachute maneuverability and accuracy is the turning rate. A fast horizontal velocity is of little use if the parachutist cannot steer the parachute in the desired direction. The turning rate measures how quickly the jumper can change direction to steer towards his desired landing point or to avoid an obstacle or other parachutists. Together, a high effective drag coefficient and a high turn rate mean a highly maneuverable parachute. This maneuverability has benefits in addition to accuracy; it also can be translated into greater safety. Reference 7 indicates that drowning due to unintentional water landings is a leading cause of parachuting fatalities. Highly maneuverable parachutes significantly reduce the probability of such landings. A further note of equal importance is that high horizontal velocity and the ability to steer into the wind can significantly reduce the impact when landing in high surface winds and thereby reduce the probability of injury.

C. DELIVERY FLEXIBILITY

The final parameter, used by the author, to determine parachute effectiveness is a measure of Delivery Flexibility. The method designed for evaluating the Delivery Flexibility in this analysis was to compare each alternative system to the number of different types of aircraft that could be used to deliver a team of parachutists to the objective area, the range of altitudes from which it is operationally sound and prudent to jump (exit an aircraft in flight), and the range of air speeds at which it is safe to exit the aircraft. Details of the methods used to develop these ranges and rate the alternative parachute systems are contained in Appendix C. The justification for the inclusion of these criteria is that a commander may be extremely limited in an operational situation as to a method and size of insertion of his reconnaissance team. If the parachute available to him is incompatible with the insertion method, he will be denied the intelligence these reconnaissance personnel could have provided. Thus, it is desirable to have parachuting equipment that is not limited to a specific delivery vehicle, but is versatile. In Appendix C each alternative canopy assembly has been assigned a score of weight by the author based on how flexible it is in adapting to alternate delivery means.

D. EFFECTIVENESS MODEL

Once the relative measures for effective drag coefficient, turning rate, and delivery flexibility are determined, a model can be constructed for the measurement of overall

effectiveness. Since there is no indication, to the author, that a previous attempt has been made to construct such a quantitative model, and due to time and resource limitations, there is no capability for testing it, the only basis available for weighting the various parameters are subjective. Rather than attempt such a weighting scheme based on limited experience and intuition, the weight assigned each parameter will be equal. (The author recognizes that by assigning a weight to any particular parameter, thereby not making that parameter equal, the results in the model utilized herein will change thereby possibly leading to a different conclusion and recommendation.) Continuing, in order to do this, it was necessary to make sure that the choice of units did not influence the weighting of the parameters. The method used here will be to report, for each of the three parameters, the results obtained for each of the parachutes (considered to be adequate for a military application) then convert these figures to scores which show how each parachute compares to a base parachute, the MC1-1. The following formula will be used to compute the Effective Drag Score for the j(th) parachute:

$$(2) \qquad D'_j = \frac{D_j}{D_{base}} \times (100)$$

D_j = *Effective Drag Coefficient for the j(th) parachute

D'_j = Effective Drag Coefficient Score for the j(th) parachute

*Effective Drag Coefficient is synonymous with lift to drag (L/D) in this study.

D_{base} = Effective Drag Coefficient for the base parachute, MC1-1

The formula for Turning Speed, W_j, and Delivery Flexibility, F_j, are similar, simply replacing D_j and D_{base} with the appropriate variables.

Once each of these factors has been calculated, the overall effectiveness of each parachute is given by the formula:

$$E_j = \frac{D'_j + W'_j + F'_j}{3} \qquad (3)$$

Dividing by 3, the factor E_j is again normalized so that $E_{base} = 100$. This is done in order to identify increases and decreases in effectiveness as compared to the currently utilized static-line operated MC1-1. A similar procedure will be used later for cost data to provide a convenient Cost-Effectivenesss Index. The results of the parachute effectiveness comparisons are shown in table 7-1.

PARACHUTE EFFECTIVENESS

Alt. j	Nomenclature	Effective Drag Coefficient $*D_j$	D'_j	Turning Rate deg/sec $*W_j$	W'_j	Delivery Flexibility $*F_j$	F'_j	Overall Effectiveness E_j
1	T-10	.3	40	12	29	24	100	56
2	MC1	.69	92	23.6	58	24	100	83
3	MC-1	.75	100	40.7	100	24	100	100
4	28' Flat	.71	95	56.5	139	36	150	128
5	MC3	1.16	155	90	221	36	150	175
6	Para-Plane	2.5	333	72	177	27	113	208
7	Para-Foil	3.12	416	40	98	23	96	203
8	Para-Wing	1.69	225	102	250	36	150	208
9	Strato-Star	2.5	333	72	177	27	113	208
10	Strato-Cloud	2.5	333	72	177	27	113	208

*Figures shown in these columns are derived from information found in the Appendices.

Table 7-1

VIII. COST ANALYSIS

The second major portion of this system analysis is determination and analysis of the costs involved in each of the various alternatives under study. In order to provide the decision maker with cost information that is meaningful and useful in comparing various levels of effectiveness with their respective costs, it was decided to present cost data in a similar format. The objective is to arrive at a cost "score" or "ratio" that would provide a Cost-Effectiveness Index for each parachute. These cost scores will be the ratios of the present value of all the costs of each of the alternatives as compared to the total present-value of the costs for a base parachute. Once again, the base parachute selected is the system currently in service--the MC1-1.

Before beginning a detailed examination of the actual dollar costs, it was necessary to establish a rationale for deciding which costs to include. Obviously, to determine cost ratios between the base system and the other alternatives, it was not satisfactory to limit costs considered to the incremental costs between the base system and the alternatives as this would result in infinite ratios as the denominator of the ratio would be the "difference" between the cost of the base parachute and itself. This "difference" would always be zero and would make it impossible to compute a ratio.

At the other extreme would be the inclusion of all costs for each system. This appears to be equally unsatisfactory because it would result in allocation of sunk costs such as facilities and buildings which are necessary to support each of the alternative parachute systems, including the base system. The problem with including such "sunk" costs is that they have already been either spent or committed and can in no way be affected by decisions rendered herein as to the selection of an alternative or even by a decision to do away with parachutes altogether.

The costs for each alternative addressed here are the variable costs, those that could be affected by the final decision. These variable costs are broken down into the following categories for each alternative: procurement cost (unit purchase price), training costs, recurring (operating) costs, and the expected costs of casualties. In each case, wherever applicable, future alternative costs are discounted to present value in accordance with Table 1 of the "Economic Analysis Handbook," [Ref. 8] and DOD Instruction 7041.3 [Ref. 9].

A. PROCUREMENT COSTS

The procurement cost data used in this analysis and listed below was obtained from the Airborne Department, U. S. Army Quartermaster School, Fort Lee, Virginia (items marked *). Cost information for items marked ** were obtained from certified commercial sources [Ref. 10]. All the costs include a complete parachute assembly (harness, back pack,

tray, deployment bag, and canopy). The costs indicated for each parachute in Table 8-1 do not reflect any possible discount which might be obtained in connection with a large scale government procurement or other contract negotiations.

B. TRAINING COST

The training costs to be considered are the costs of providing parachute training for the members of the Force Reconnaissance Company in order to qualify them to carry out the mission described in paragraph II. Costs considered are limited to those directly related to parachuting, being careful not to include the costs of other training received (Basic Training, infantry tactics, swimming, etc.) as these exist independently of parachuting and therefore are, for the purposes of this study, not varible.

An assumption is made that the cost of training military parachutists to use a static-line parachute assembly is the cost of training a student at the U. S. Army Basic Airborne School, Fort Benning, Georgia. The cost of training a Marine for free fall parachuting is the aforementioned cost plus the cost of training a student at the Military Free Fall Parachute School, Fort Bragg, North Carolina. These costs are $630.00 and $6,308.00 respectively and represent the costs of operating the schools on a per student basis [Ref. 11]. This assumption means that the author is ignoring the salary of the student during the time of the training. This is considered reasonable because, even though it can be argued that he is unable, during the duration of his training,

to work or produce for his unit, he would be on duty and drawing pay while performing this duty. Further, the manning level of his unit is not inflated or increased to provide a replacement for him while he is at school. If there is a cost to the unit due to his absence, it is probably in the nature of a slight degradation in unit integrity and some lessening in overall proficiency due to his absence from other training. These costs, however, are not readily available and are considered to be slight in comparison to school costs.

Another implication of this assumption is that no additional training is necessary to prepare Marines for the mission described in paragraph II. This is done mainly for purposes of simplicity. Obviously, additional training is desirable, and some might argue that it is necessary to achieve teamwork and unit proficiency. However, estimates of how much is necessary are subjective and go somewhat beyond the individual skill level. Clearly an individual is prepared upon completion of schooling to join a unit performing a tactical parachute operation.

It can be assumed that during the service life of a parachute, which is twelve years, [Ref. 12], new parachutists will have to be trained from time to time. Based on past experience, Marines remain on board for an average of about two years before they are transferred to other units or are released from active duty. This implies that the Marine Corps will incur training costs six times during the service life of each parachute. It cannot be determined exactly

when these expenses will be incurred over the twelve-year service life of the parachute. The procedure adopted in this analysis was to compute the total life cycle training cost for each category of parachute, static line and free fall, and find the average yearly training cost by dividing by 12. This assumes that all the training expenses are distributed uniformly over the twelve-year period, which is the case once a steady state is achieved. A discount factor is then applied to yield the present value of the twelve year service life of a parachute. This discount factor, taken from the Attachment to enclosure (2) of DOD Instruction 7041.3, is 7.149 [Ref. 3]. Life cycle training costs appear in Table 8-2. The costs, in Table 8-2, $2251 (for a basic static line parachutist) and $24,799 (for a free fall qualified parachutist) are the costs of training one Marine parachutist, officer or enlisted, for each jump billet (or parachute) in the unit, for a period of twelve years.

C. CASUALTY COSTS

Casualty costs can be divided into (a) fatalities costs, and (b) injuries costs. Marine Corps Order 5100.8C dated 6 June 1972, establishes the cost figure to be used in relation to a fatality as $65,200. For injuries, the same Marine Corps Order establishes the cost of bringing personnel out of service 24 hours or more, amounts to $2,300.00 per 24 hour period.

Statistical information with regards to fatalities and injuries for two of the parachutes included in this study

is listed in Table 8-3. Based on the figures in Table 8-3, the expected yearly costs of fatalities and injuries per parachute can be calculated. Each parachutist in the Force Reconnaissance Company is equipped with one main parachute, one reserve parachute, and is required to make at least one proficiency parachute jump per quarter. Based on the author's experience of four years (1957 - 1961) in Force Reconnaissance, the average is two jumps per quarter. Thus, the total number of times a parachute is used for parachuting purposes each year is eight. Calculations for expected fatalities and injuries costs appear in Table 8-4.

As was previously mentioned in the training cost section of this analysis, the service life of a parachute is twelve years. Based on Attachment 4, Enclosure 2, of DOD Instruction 7041.3, the factor to be used for 10% annuity over twelve years is 7.149. The present value of the computed cost figures, given a twelve year service life would be:

	T-10	MC1-1
Fatalities Costs:	($0.0)7.149 = 0	($8.90)7.149 = $63.62
Injuries Costs:	($1.90)7.149 = $13.58	($1.99)7.149 = $14.22

Because of the reliability constraint given for the parachutes included in this analysis, there is a strong reason to assume that the fatalities and injury figures will not vary significantly among the different parachutes. The costs computed above for T-10 and MC1-1 will thus closely indicate within which range the comparable costs for the other parachutes will fall.

Compared to the other cost categories included in this study, the casualty costs will be of minor significance in the selection and decision process. In addition, information for most of the parachutes is not available or does not exist. We, therefore, consider it justified to exclude those costs from further analysis.

D. RECURRING (OPERATIONS) COSTS

1. Background

It must be emphasized that the parachute rigging functions are the significant and relevant operating costs. Rigging functions include packing, inspection, and repair of parachutes; rigging is done by "riggers" (identified in the Marine Corps by Military Occupational Specialty 7141). Labor costs for riggers constitute almost all of the rigging function costs; material costs are comparatively small. There is no noticeable difference in maintenance between the MC1-1 and MC3 parachutes [Ref. 14]. During a telephone interview with the Operations Staff, National Parachute Test Range [Ref. 15], the point was made that, ceteris paribus, there is usually no difference in maintenance requirements regardless of parachute type. On the basis of the foregoing, it is assumed in this analysis that parachute maintenance requirements will not vary among canopy types. This assumption is corroborated by the information received from rigging personnel at Fort Bragg and Camp Lejeune, North Carolina. Training costs for parachute riggers are also considered to be part of recurring (operations) cost.

2. Personnel Costs

The current table of organization for the Force Reconnaissance Company provides for ten, 7141, riggers to perform parachute packing, maintenance and inspection for the parachutes on charge to the Force Reconnaissance Company [Ref. 16]. It was determined by the author that the most accurate basis for computing personnel costs for rigging functions would be to use Manning Level (ML) strength vice T/O. ML strength can be considered constant regardless of types of canopies being used, and reflects actual labor effort. Personnel costs set out below are for a one year period. "Time in grade" for basic pay computations is based on personnel experience of the author as a former commanding officer and other knowledgeable Marine officers. Allowances include subsistance and quarters, but exclude separation and special/proficiency pay since a reasonable approximation of these amounts cannot be estimated. Separation and special/proficiency amounts are a small percentage of total pay. These amounts may or may not be paid depending on the individual Marine. Table 8-5 describes the current yearly total, pay and allowances, for the rigger personnel assigned, by ML, to the Force Reconnaissance Company.

3. Maintenance and Repair Costs

As previously stated, personnel labor costs constitute the major portion of daily repair and maintenance activity. In addition to labor costs, material costs of parachute repair can be considered. Currently in the Marine Corps, a parachute requires repair approximately two

out of every fifteen jumps; however, the cost of materials per repair is not recorded [Ref. 17]. This cost, nevertheless, is considered very small. The foregoing information tends to substantiate [Ref. 18] which provided an average material cost of $1.50 per repair.

4. Rigger Training Cost

The turnover rate for rigging personnel is basically the same as the personnel turnover rate throughout the Marine Corps--approximarely, once every two years. Although not all rigging personnel will leave the Marine Corps or require retraining, the necessity of maintaining a pool of trained rigging personnel to support T/O requirements makes the assumption of a two year turnover rate reasonable and, most likely, conservative. Total number of riggers that should be trained over a twelve year period is 24. The Marine Liaison, Army Quartermaster School, Fort Lee, Virginia furnished a training cost of $2,511[3] per rigger [Ref. 19]. This amount represents the costs of operating the school on a per student basis. The salary of the student is ignored for the reasons set forth in the explanation of parachutist training costs (paragraph VIII-A). Since rigger training costs are incurred over the economic life of a parachute (12 years), the annual rigger training costs must be appropriately discounted. The 10% discount rate required by

---

[3]This figure is based on 1976 dollars and is the total costs (direct and indirect--not including pay and allowances) for each student attending the Parachute, Packing and Maintenance Course, Fort Lee, Virginia.

current directives will be used. The derivation of the present value factor used for computing discounted life cycle cost is discussed in the parachutist training cost portion of the cost analysis.

5. Other Operating Costs

Overhead, supplies, and utilities cost information is not available, and is not expected to vary according to the decision for selection of the optimum parachute canopy(ies). Maintenance and repair equipment (e.g., sewing machines and tool kits) are already available; therefore, they are considered sunk costs. It is anticipated that there will be no additional equipment requirements if a parachute canopy, other than those already in the supply system, is selected.

6. Life Cycle Cost Calculation Per Parachute

Calculation of the yearly operating cost per parachute is derived from the operating information received from maintenance personnel in the Air Delivery Platoon [Ref. 17] and 2d Force Reconnaissance Company, Camp Lejeune, North Carolina [Ref. 20]. There are 86 parachutes; each parachute is jumped an average of 8 times per year for a total of 688 jumps. The present value factor for the 12 year recurring personnel and material costs is derived from Table B of DOD Instruction 7041.3 [Ref. 3].

a. Annual personnel cost per parachute:

$$(4)\quad \frac{\text{Total yearly personnel cost}}{\text{Total parachutes maintained}} = \frac{\$34{,}728}{86} = \$403.80/\text{parachute.}$$

b. Annual average material cost per parachute:

(5)

$$\frac{\text{(Total number jumps/year)(Repair rate)(Average cost per repair)}}{\text{Total parachutes maintained}}$$

$$\frac{(688)(2/15)(\$1.50)}{86} = \$1.60/\text{parachute}$$

c. Total annual maintenance and repair cost per parachute:

(6)

Subpara. a + Subpara. b = \$403.80 + \$1.60 = \$405.00*/parachute

d. Total average annual rigger training cost per parachute:

(7)

$$\frac{\text{(Training cost/rigger)(Tot. no. riggers trained over econ. life)}}{\text{(Tot. parachutes maintained)(Tot. yrs econ. life per parachute)}} =$$

$$\frac{(\$2511)(24)}{(86)(12)} = \$58^{*}/\text{parachute}$$

e. Total economic life cycle cost per parachute for recurring (operations) costs:

(8)

(Subpara. c) + (Subpara. d)(Discount factor of 10% for 12 yrs) =

(\$405 + \$58)(7.149) = (\$463)(7.149) = \$3310*/parachute

*rounded off

E. SUMMARY OF COST DATA

The costs discussed and computed in this section of the analysis are summarized in Table 8-6. The relative ranking column in Table 8-6 is computed as follows: the parachute MC1-1 is selected as the base parachute. The total cost figure for each parachute is divided by the total cost of the base parachute and multiplied by 100. Example:

(9)

$$C_j = \text{Rel Ranking} = \frac{\text{Total Cost T-10}}{\text{Total Cost MC1-1}} \cdot 100 = \frac{5{,}942}{5{,}990} \cdot 100 = 99.7.$$

PARACHUTE COST TABLE		
Type of Parachute	Cost Complete Assembly $	Free Fall (FF) Static Line (SL)
* T-10	381	SL
* MC1	429	SL
* MC1-1	425	SL
* 28' Flat	505	FF
** MC3	800	FF
** Para Plane	775	FF
** Para Foil	680	FF
* Para Wing	505	FF
** Strato Star	550	FF
** Strato Cloud	750	FF
(The above figures do not include a reserve parachute)		

Table 8-1

The cost information obtained from commercial sources (**) do not include additional costs that might be caused by any modifications that the government might require in order to satisfy MILSPEC.

LIFE CYCLE TRAINING COSTS STATIC LINE AND FREE FALL					
Category	Average Annual Cost	X	Discount Factor	=	Life Cycle Training Cost
Static Line	$\frac{(\$630)\ (6)}{12}$	X	7.149	=	$2251
Free Fall	$\frac{(\$630 + \$6308)(6)}{12}$	X	7.149	=	$24,799

Table 8-2

FATALITIES AND INJURIES FOR THE T-10 AND MC1-1 [Ref. 13]					
Type of Parachute	Number of Jumps in Year				Total
	1972	1973	1974	1975	
T-10	229,917	204,683	165,856	132,947	733,403
MC1-1	37,926	38,193	39,929	59,749	175,797
Type of Parachute	Total Number of				
	Fatalities		Injuries		
T-10	0		76		
MC1-1	3		19		

Table 8-3

EXPECTED FATALITIES AND INJURIES COSTS PER PARACHUTE	
Expected yearly fatalities costs:	
<u>T-10</u>	<u>MC1-1</u>
$\left(\frac{0}{733,403}(\$65,200)(8)\right) = \$0.0$	$\left(\frac{3}{175,797}(\$65,200)(8)\right) = \$8.90$
Expected yearly injuries costs:	
<u>T-10</u>	<u>MC1-1</u>
$\left(\frac{76}{733,403}(\$2300)(8)\right) = \$1.90$	$\left(\frac{19}{175,797}(\$2300)(8)\right) = \$1.99$

Table 8-4

PAY AND ALLOWANCES FOR RIGGER PERSONNEL IN THE FORCE RECONNAISSANCE CO					
Billet	Grade	Time	Monthly Basic Pay	Monthly Allowances	Yearly Total
Loft NCO	E-5	Over 6	$574	$239	$9,756
Rigger	E-5	Over 4	539	239	9,336
Rigger	E-4	Over 3	486	220	8,472
Rigger	E-3	Over 2	441	156	7,164
					$34,728

Table 8-5

SUMMARY OF COST DATA					
Type of Chute	Training Cost $	Procurement Cost $	Operation Cost $	Total Lifecycle Cost $	REL Ranking
T-10	2251	381	3,310	5,942	99.7
MC1	2251	429	3,310	5,990	99.2
MC1-1	2251	429	3,310	5,990	99.2
28' Flat	24,799	505	3,310	28,614	478.02
MC3	24,799	800	3,310	28,709	479.6
Para Plane	24,799	775	3,310	28,884	482.5
Para Foil	24,799	680	3,310	28,789	480.9
Para Wing	24,799	505	3,310	28,614	478.0
Strato Star	24,799	550	3,310	28,659	478.8
Strato Cloud	24,799	750	3,310	28,859	477.6

Table 8-6

IX. EVALUATION

A. CONSTRAINTS

Having analyzed the costs and benefits attributable to each parachute, we are ready to evaluate the alternatives as to their relative cost effectiveness. Before evaluating, however, it is necessary to examine each of the alternatives to ascertain whether or not all constraints are met by each. Taken in the order of Table 7-1:

1. T-10. Meets all constraints.

2. MC1. Meets all constraints.

3. MC1-1. Meets all constraints.

4. 28' Flat. Does not meet reliability criterion due to insufficient testing under controlled military conditions.

5. MC3. Meets all constraints.

6. Para Plane. Does not meet reliability criterion due to insufficient testing under controlled military conditions.

7. Para Foil. Does not meet stability criterion due to dangerous stall or high sink characteristics even though this is a controlled maneuver. Does not meet reliability criterion due to insufficient testing under controller military conditions.

8. Para Wing. Does not meet reliability criterion due to insufficient testing under controlled military conditions.

9. Strato Star. Does not meet reliability criterion due to insufficient testing under controlled military conditions.

10. Strato Cloud. Does not meet reliability criterion due to insufficient testing under controlled military conditions. Does not meet lift capacity; limited to a maximum suspended weight of 250 lbs.

B. COST EFFECTIVENESS

Elimination of those parachutes that do not satisfy all constraints leaves the T-10, the MC1, the MC1-1, and the MC3. In almost all cases of elimination, the immediate cause was insufficient testing. For this reason, it was decided to continue to evaluate all parachutes, thus assisting in deciding whether or not additional testing appears to be warranted. As indicated in paragraph 5, above, the objective is to obtain a measure of cost-effectiveness for each parachute by computing a Cost-Effectiveness Index, for each parachute, as shown below.

$$CEI = \frac{E_j}{C_j} \qquad (10)$$

Taking the results, E_j and C_j, from Tables 7-1 and 8-1, the CEI's have been calculated and are shown in Table 9-1. Based on the results of the computations and displayed in Table 9-1, some preliminary evaluations/conclusions can be made. The most cost effective parachute (based on the effectiveness model of paragraph VII-D and the cost findings of paragraph VIII) is the MC1-1, the model currently in use. It is more than twice as "cost effective" as the best free fall model, the para-wing, and almost three times as "cost

effective" as the only free fall parachute which satisfied all of the constraints. No further or firmer conclusions will be drawn until after analyzing why this appears to be so and what adjustments in models or computations might lead to a different result/conclusion.

Cost-Effectiveness Index				
j	Nomenclature	E_j	C_j	Index
1	T-10	56	99.7	.56
2	MC1	83	99.2	.83
3	MC1-1	100	99.2	1.00
4	28' Flat	128	478.02	.26
5	MC3	175	479.6	.36
6	Para Plane	208	482.5	.43
7	Para Foil	203	480.9	.42
8	Para Wing	208	478.0	.43
9	Strato Star	208	478.8	.43
10	Strato Cloud	208	477.6	.43

Table 9-1

X. SENSITIVITY ANALYSIS

A. SENSITIVITY OF RESULTS TO MODIFICATIONS IN EFFECTIVENESS MODEL

This section will be devoted to determining what modifications of our effectivenesss model,

$$E_j = \frac{D'_j + W'_j + F'_j}{3}$$

would have to be made in order to make alternative #5, the MC3 free fall parachute, achieve a Cost Effectiveness Index equal to that of the currently best alternative, the MC1-1. This section will consider costs, as determined in paragraph VIII of this analysis, as fixed.

To make the MC3 equally cost effective as the MC1-1, we would have to raise E_5 from being 1.75 times as great as E_3 to a level 4.79 times as great. This is a 260% increase. Since the ratios of individual effectiveness factors as presently computed are 1.55 for D_j, 2.22 for W_j, and 1.5 for F_j, such as increase is impossible through the use of a simple weighting scheme that adjusts the relative importance of the factors. The only alternative then is to find a new basis for computing the factors or scores themselves. We will go through two methods that will accomplish this task and make comments as to their relative strengths and weaknesses.

The first method is to modify all three parameter scores before averaging them. In this way, each one is equal to

4.79 so their average is again 4.79. The computations will be simpler if the factors are divided by 100 and then multiply the result by 100. Thus we will have attained:

$$E'_j = 100\left(\frac{\frac{D'_j}{100} + \frac{W'_j}{100} + \frac{F'_j}{100}}{3}\right) \tag{11}$$

which is clearly the equivalent to the original model. Each parameter will now be examined based on the above model.

1. Effective Drag

Since the raw data used to calculate the factors in the original model is fixed and widely accepted, it is necessary to modify the importance (effectiveness) that is related to the various levels of D' such that a 55% increase in D' will appear 4.79 times as desirable or effective. Some possible ways to do this are:

a. Make up the entire difference by placing the appropriate exponent on D'_j. The exponent, X, is found as follows:

$$\left(\frac{D'_5}{100}\right)^x = \left(\frac{155}{100}\right)^x = 1.55^x = 4.79$$

$$x = \frac{\ln 4.79}{\ln 1.55} = 3.57$$

The model then would be:

$$E = 100\left(\frac{\frac{D'_j}{100}^{3.57} + \frac{W'_j}{100} + \frac{F'_j}{100}}{3}\right)$$

Similar methodology could be used for Turning Rate and Flexibility. This approach, however, is not considered sound. There is no inherent justification and the implications are that further increases in D'_j would lead to phenomenal increases in E_j. It does not seem reasonable that a D'_j of 200 is 11 times as desirable as a D'_j of 100, or that a D'_j of 300 is 44 times as desirable.

b. Use of a logarithmic approach. It is reasonable to consider a logarithmic function in which increases in D', W', and F' at low levels contribute more to effectiveness than similar sized increases at higher levels. Basically, what is desired is a function in which the following conditions are true:

$$f \frac{D'_{base}}{100} = f(1) = 1$$

and

$$f \frac{D'_5}{100} = f(1.55) = 4.79$$

These conditions are satisfied in $f(D'j) = 1 + K_d \ln D'_j$ where D'_5 is 1.55 and K_d is found by

$$(12) \qquad K_d = \frac{4.79 - 1}{\ln 1.55} = \frac{3.79}{\ln 1.55} = 8.64$$

The other factors are found similarly.

$$(13) \quad K_w = \frac{3.79}{\ln 2.21} = 4.79 \quad \text{for the Turning Rate term}$$

$$(14) \quad K_f = \frac{3.79}{\ln 1.5} = 9.34 \quad \text{for the Flexibility term}$$

The resulting model is:

$$E_j = \frac{100}{3}\left[\left(1+8.64 \ln \frac{D'_j}{100}\right) + \left(1+4.79 \ln \frac{W'_j}{100}\right) + \left(1+9.34 \ln \frac{F'_j}{100}\right)\right]$$

$$E_5 = \frac{100}{3}\left[4.79 + 4.79 + 4.79\right] = 479$$

Simplified:

(15)

$$E_j = 100 + 33.3 \ln \left[\left(\frac{D'_j}{100}\right)^{8.64} \left(\frac{W'_j}{100}\right)^{4.77} \left(\frac{F'_j}{100}\right)^{9.34}\right]$$

This resulting model is more appealing than the original in that it does not require the assumption that effectiveness increases linearly with incremental additions for the parameters included. The model allows for decreasing marginal utility for all three factors. However, there are other models which could be formulated that could have this general characteristic and meet the same initial conditions. There is little reason to believe that this model is the correct model when compared to the original model. The point is the final result can vary greatly depending on whether a linear model is selected or some other model.

The second general approach in determining a model that would yield a Cost Effectiveness Index for the MC3, that is comparable to the MC1-1, changes only the Delivery Flexibility factor F_j. The method here is to increase the weighting of those "X" markings described in the method of Appendix C that are unique to free-fall

parachutes. There is some rationale for such a weighting scheme within the delivery flexibility analysis. For example, suppose all the delivery possibilities common to both static line and free fall parachutes, i.e., exit velocity under 150 KIAS and altitudes up to 10,000 feet, are ruled out by some tactical reason. In such cases, assuming the mission assigned is important, the Commander is likely to want to increase the degree of importance he places on "X's" in those Appendix C grid squares that relate to airspeeds greater than 150 KIAS and altitudes above 10,000 feet. This portion of the analysis will examine how sensitive E_j is to variations in the weighting of those delivery capabilities. Phrased differently, this attempt or approach will determine what weighting must be applied to these points to make the overall Cost Effectiveness Index for the leading free-fall parachute the same as that for the MC1-1.

The Cost Effectiveness Index for the MC1-1 is equal to 1. In order to achieve a Cost Effectiveness Index for the MC3 equal to 1 without adjusting cost, the Effectiveness Score must be raised to 479, the same as the Cost Score by adjusting only the Delivery Flexibility Score.

$$E_5 = 479 = \frac{155 + 221 + F'_5}{3}$$

$$F'_5 = 3(479) - 155 - 221 = 1061$$

From the formula used in Appendix C:

$$F'_j = \frac{F_5}{F_{base}} \times 100 \qquad (16)$$

$$F_5 = \frac{1061(24)}{100} = 255$$

The tabs to Appendix C show that there are 24 grid squares marked for both MC1-1 and MC3: this means that an increased weighting of the remaining 12 marked grid squares for the MC3 flexibility grid must make up the difference of:

$$255 - 24 = 231$$

In other words, we must weight these grids as being $\frac{231}{12}$ = 19.25 times as important as the grids common toboth. This yields:

$$F_5 = 24 + 19.25\ (12) = 255$$

$$F'_5 = \frac{255}{24} \times 100 = 1061$$

$$E_5 = \frac{155 + 221 + 1061}{3} = 479 \quad \text{Check.}$$

The implication of all this is that for a decision maker to accept the premise that the extended delivery flexibility of the free fall parachutes, is, all by itself, sufficient to make them cost effective. It is evident that those portions of the flexibility spectrum limited to free fall parachutes

only, are, at least 19.25 times as important as those portions common to both static line and free-fall parachutes.

Extension of this line of analysis, and to a limitation in the types of aircraft available, to those which may be operated from aircraft carriers, shows 15 points common to both static line and free fall and 8 points unique to free fall. This leads to a weigting factor of $\frac{255 - 15}{8} = 30$, or the conclusion that these points unique to free fall parachutes would have to be at least 255 times as important as the other points in order to make the MC3 free-fall parachute equally cost-effective.

B. SENSITIVITY OF RESULTS TO COST REDUCTION

It is clear from the Summary of Cost Data displayed in Table 8-6 that the training costs are the "critical" life cycle costs. Recurring (operating) costs are constant for all parachutes; procurement costs, ranging from $381 to $775 (Table 8-1), are inconsequential relative to total life cycle costs (Table 8-2). The noticeable difference is in life cycle training costs between static line ($2,251) and free fall ($24,799) parachutes (Table 8-2). The purpose of this portion of the sensitivity analysis is to determine the amount by which life cycle training costs must be reduced in order to make free fall parachutes at least as equally cost effective as the base parachute (i.e., MC1-1).

In order for a parachute to be at least as cost effective as the MC1-1, the effectiveness index must equal the cost index to result in a cost-effectiveness index equal to "1"

(the cost-effectiveness index of the MC1-1). In formula form, this can be expressed as:

$$\text{(17)} \qquad \frac{\text{Cost Index}}{\text{Effectiveness Index}} = 1$$

or restated:

$$\text{Cost Index} = \text{Effectiveness Index}$$

From the Cost Analysis portion of this study, it is known that the left hand portion of the equation can be expressed as:

$$\text{(18)} \qquad \frac{Cp_j + Co_j + M_j}{C_{B_j}} = E_j$$

The Summary of Cost Data (paragraph VIII.E) and Table 8-6 provide the specific cost data where C_B is the total life cycle cost of the MC1-1. Cp_j is the procurement cost of the jth parachute, Co_j is the life cycle operating cost of the jth parachute, and M_j is the maximum life cycle training cost which may be incurred before the jth parachute ceases to be more or equally cost effective when compared to the MC1-1. E_j is the effectiveness index for the jth parachute. Table 10-1 is constructed by solving for M_j. The R_j column of the table shows the total amount by which the life cycle training costs must be reduced to obtain M_j; hence, R_j is the amount we are seeking. R_j is derived as follows:

$$(19) \qquad R_j = C_j - (Cp_j + Co_j + M_j)$$

where C_j is the calculated total life cycle cost of the jth parachute.

Table 10-1 shows that the amounts by which life cycle training cost must be reduced in order to make free fall parachutes comparatively cost-effective when compared to the MC1-1, which are relatively large. The only apparent practical way to reduce training costs for free fall parachutes is by reducing free fall jump training costs. The major elements of this cost are aircraft operating cost and duration of the training period. The current training program at Fort Bragg, North Carolina, is four weeks long [Ref. 11]. Part of the syllabus involves airborne operations and tactics which are not directly applicable to the Marine Corps. The aircraft used for jumping is the Air Force's C-141. In view of the foregoing, it may be practical for the Marine Corps to inaugurate its own free fall jump training program. In this way, the aircraft operating costs and school length can both be reduced. Use of helicopters in lieu of fixed wing jet aircraft will most likely result in a great reduction in aircraft operating costs. Also, it may be possible to reduce the training period length to as short as one week. (This is based on the personal opinion of some experienced jumpers, and has not been verified by any particular study).

As an addition to this portion of the sensitivity analysis, it is deemed appropriate that a maximum free fall jump training program cost per parachutist be calculated. If the Marine Corps finds that by utilizing its own internal assets, it can accomplish the necessary free fall jump training at a satisfactory low cost per parachutist, then the life cycle training costs per free fall parachute may become more reasonable for the gain in effectiveness for free fall parachuting over static line parachuting.

To determine the approximate maximum free fall training cost per parachutist that would be incurred by the Marine Corps, providing that all other costs remain fixed, the training cost calculation method in paragraph VIII.A of the Cost Analysis can be used with some slight modification. It has already been shown that the life cycle training cost (C_T) is equal to static line parachute training costs (T_{SL}) plus free fall parachute training cost (T_{FF}) and divided by the number of years of economic life and multiplied by the number of parachutists trained and the appropriate present value factor. The number of parachutists trained is 6, and the present value factor is 7.149 (12 years at 10%). Expressed as an equation:

$$C_T = \frac{(T_{SL} + T_{FF})(6)}{12}(7.149) \tag{20}$$

T'_{FF_j}, rather than T_{FF}, is the amount desired. This computation provides <u>the maximum free fall parachute training</u>

cost per parachutist which can be incurred by the Marine Corps for the jth parachute before training costs cause the whole cost index to exceed the effectiveness index for that parachute. Table 10-2 is a summary of the free fall training cost for each parachute under consideration. Since basic parachute jump training (T_{SL}) can be assumed to continue under Army institution, that amount will remain constant as \$630. C_T will be replaced by M_j which is the maximum life cycle training cost which can be incurred before the jth parachute ceases to be more or equally effective when compared to the MC1-1. M_j is taken from the prior calculations made in this section of the sensitivity analysis. The modified formula is, therefore, as follows:

$$M_j = \frac{(\$630 + T'_{FF_j})(6)}{12}(7.149) \tag{21}$$

or restated:

$$\frac{12}{6}\left(\frac{M_j}{7.149}\right) - \$630 = T'_{FF_j} \tag{22}$$

LIFE CYCLE COST OF PARACHUTES UNDER CONSIDERATION SUMMARY		
Parachute	M_j	R_j
28' Flat	\$4,250	\$20,549
MC3	7,117	17,682
Para Plane	8,958	15,841
Para Foil	8,801	15,998
Para Wing	9,291	15,508
Strato Star	8,958	15,841
Strato Cloud	8,958	15,841

Table 10-1

SUMMARIZED FREE FALL TRAINING COSTS	
Parachute	T'_{FF}
28' Flat	\$ 559
MC3	1,361
Para Plane	1,876
Para Foil	1,832
Para Wing	1,969
Strato Star	1,876
Strato Cloud	1,876

Table 10-2

XI. CONCLUSION

The objective of this analysis was to determine and recommend the optimal parachute to be utilized by Marine Corps Force Reconnaissance companies based on performance characteristics and relative costs. As a result of the foregoing evaluation and sensitivity analysis, it appears that currently static line parachutes are more cost effective than free-fall parachutes primarily due to the high training costs associated with free-fall parachuting. There are situations, however, in which free-fall parachutes are the only feasible means of insertion. The decision maker's selection must be highly dependent on his perception as to the likelihood of such a situation.

The MC1-1 parachute was found to be the optimal parachute for use by Force Reconnaissance personnel if both effectiveness and cost must be considered. If cost is not an important consideration, the MC3 free-fall parachute is the best proven parachute currently available that meets military specifications.

Many of the parachutes initially considered were eliminated from contention because, even though they had several desirable characteristics, they had not been proven to be reliable by testing under controlled military conditions. Actually, these parachutes may be sufficiently reliable. If proven to be so, one of them could be found to be the most effective of all the parachutes considered.

The MC3 Military Free-Fall parachute system represents a major advance in design, significantly surpasses Army system performance requirement [Ref. 3], and can substantially enhance the capability of select elements of the U. S. Marine Corps Force Reconnaissance Units for operations which require the employment of military free-fall techniques.

Although the MC1-2 Military Free-Fall parachute system met many of the Army requirements [Ref. 3], its rate of turn and other performance characteristics provide significantly less operational capability than that of the MC3 Military Free-Fall Parachute System. This relatively lower performance of the MC1-2 Military Free-Fall Parachute System, however, may be beneficial during initial training of student military free-fall parachutists [Ref. 21].

XII. RECOMMENDATIONS

Possessing a sufficiently sized free fall parachute-qualified force within the Force Reconnaissance Company would provide a capability greatly enhancing the mission assigned to the Force Reconnaissance Company and enlarge the scope of operation involving amphibious forces and reinforce current U. S. Marine Corps fiscal constraint.

It is recommended that the MC1-1 parachute be retained as the primary parachute for operations and training use with Marine Corps Force Reconnaissance Companies. However, the author strongly feels that the Marine Corps should also develop a free-fall parachuting capability within the Force Reconnaissance Company in order to provide an additional degree of flexibility in mission performance as eluded to in the preceding paragraph. At least one full reconnaissance team in each Force Reconnaissance Company should have a free-fall parachute capability. The MC3 parachute is recommended for such purposes.

Additionally, it is felt that personnel that are free-fall qualified should be recognized as such, therefore, it is recommended that free-fall qualified (e.g., HALO, MC3, etc.) Marine parachutists be so designated by the MOS (Military/ Occupational Specialty) 9955.

It is also recommended that the Marine Corps investigate other methods of providing the training required for Marine Corps free-fall parachute operations. If the cost per

student could be held to approximately $1700-$1900, free-fall parachuting would be equally cost effective as static-line parachuting while adding a degree of flexibility to means of inserting Force Reconnaissance personnel.

Finally, it is recommended that additional test data be acquired for those parachutes which did not meet reliability constraints because of insufficient testing in order that their actual reliability can be determined. This additional data could possibly lead to recommending a different parachute assembly system.

APPENDIX A

General Discussion of Parachutes[4]

1. General. There are three basic types of steerable parachute canopies. They are the circular (parabolic) parachute canopy modified by removing portions of the canopy material, the multi-slotted parachute with aerodynamic lifting qualities, and the nonrigid airfoil-gliding parachutes.

a. Parabolic circular canopy with material removed. The initial efforts made in giving a parachute forward movement and steerability were achieved by removing material from the rear of parabolic circular canopies. It was originally believed that the air rushing out to the rear gave the canopy forward thrust in a manner somewhat similar to the thrust created when an inflated balloon is released. It has been learned, however, this effort is only partially responsible for the forward movement. Cutting portions of the material away from the rear of a (parabolic) circular canopy results in less lift in the rear half of the canopy than the lift provided by the greater lifting surface area in the front. The unmodified (parabolic) circular canopy exerts only drag or less descent. The modified canopy provides less drag or greater descent in the back half,

---

[4]The information contained in this appendix is the author's summary of the material appearing in the bibliography pertaining to the parachutes under consideration.

resulting in the overall drag of the canopy being up and forward. Control lines facilitate turning. Some canopy modifications result in faster turns than others. More importantly, some modifications allow stable turns, while others cause wide oscillation when they are turned. To land while oscillating greatly increases the chance of injury. The addition of control lines allows the parachutist to face his canopy in any desired direction and reduces the forward speed very quickly with little physical effort. Sport parachutists have been experimenting with different sizes and shapes of the openings cut into circular canopies for over 15 years. The enormity of these experiments cannot be fully appreciated unless it is realized that in 1965, there were 30,000 to 40,000 parachuting enthusiasts in over 500 sport parachute clubs throughout the country. In all but a few isolated cases, the sport parachutes used were all of a steerable design. Interest and participation in parachuting has continued to expand since 1965, and equipment design is rapidly becoming even more sophisticated. It was the consensus of opinion that the 7-gore "TU" was the best design for modifying a (parabolic) circular canopy for cmpetition jumping. To obtain better performance requires a parachute designed with aerodynamic lifting characteristics or in an airfoil configuration. Currently, the paracommander parachute assembly is rapidly becoming the most all-around popular sport parachute. The strato-star and other high performance canopies are also extremely popular among the more seasoned free-fall sport parachutists.

b. <u>Multi-slotted parachute with aerodynamic lifting qualities</u>. The standard parachute of this type is the Para-Commander (PC)(MC3) which has 23 slots through which the air captured in the canopy during descent is funneled rearward. As the air flows through the slots, an aerodynamic lift force is created over the front of the canopy. The parachute turns and brakes by use of control lines which distort the shape of the canopy in a manner similar to the circular canopies with material removed, but with greater speed and effect which can result in pronounced oscillation. Another parachute with aerodynamic lifting qualities is the Cross-Bow which is steerable in the same manner as the Para-Commander (MC3).

c. <u>Nonrigid, airfoil-gliding parachutes</u>. The most advanced deceleration devices in use today are the nonrigid, airfoil-gliding parachutes. Included in this category are the Parafoil, Para-Plane, Parawing, and the Sailwing (Appendix B). All of these devices generate lift due to their forward glide speed in a manner similar to an airplane.

(1) Except for the Parawing and Sailwing, individual cells in the shape of jet-intake scoops are joined together to create a semirigid wing which maintains its shape and rigidity due to the flow of ram air through the cells. The airfoil attitude is maintained by the suspension line lengths which hold the leading edge of the canopy somewhat lower than the trailing edge. The wing-configured device then slides or planes through the air similar to a glider. Pulling the left control line causes the trailing edge on

the left side to be deflected downwards creating additional drag. The right side then flies faster than the left causing a turn to be made to the left. Because the left, or slow side generates less lift, it tends to drop slightly giving the parachute a banking action similar to a turning airplane. Pulling the right control line results in the reverse action for a banking turn to the right. Pulling both control lines simultaneously causes both sides of the trailing edge to be deflected downwards, resulting in increased drag and loss of gliding speed. The drag produced is proportional to how far the lines are pulled. As the forward speed is reduced by the maximum braking action of both control lines, the canopy continues slowing down until at some point, it stalls. In this attitude, it loses its efficiency as a lifting device. If the control lines are not released to some degree, the device continues to sink at an increased rate of descent and since the trailing edges have been substantially deflected, it may turn to fly backwards. When this happens, steer-ability is lost and one of the wing tips usually drops down and spins around to the rear in a very fast pivoting motion similar to an airplane in a spin. This condition is extremely dangerous if there is not sufficient altitude in which to regain control.

(2) The Parawing and Sailwing utilize the gliding-airfoil concept, but do not have the numerous cells inflated by ram air. Control is accomplished in the same manner with right turns made by pulling the right control

line, left turns made by pulling the left control line, and simultaneous pulling of both control lines resulting in a braking action. Applying full brakes to the Parawing and the Sailwing results in a more rapid rate of descent and loss of control as in the case of the other nonrigid-airfoil parachutes.

2. Maneuvering the steerable parachute

a. The means for maneuvering a steerable parachute is the manipulation of the control lines. Pulling the right line causes the canopy to turn or rotate to the right. Once the line has been released, the canopy no longer rotates and moves through the air to the front at the rate of speed inherent in that particular canopy design. Pulling both control lines simultaneously reduces the forward movement of the steerable canopy. The farther down the lines are held, the greater the reduction of the canopy thrust until, in most cases, the forward movement ceases, and the parachute is descending at an increasing rate. It is the ability to limit the forward thrust of the steerable canopy which is so important in evaluating the feasibility of this type of parachute for military use. Every parachutist has the ability to stop his forward movement and drift with the wind while increasing in his descent rate, in the same manner as a parachutist using a standard T-10 by simply pulling both control lines down and holding them there. If for any reason, he should want to, a parachutist could hold the control lines down during his entire descent, as it is not a

fatiguing effort. This is not a recommended procedure as he would more than likely sustain an injury upon impact.

b. It is easiest to understand the maneuvering of a steerable parachute by comparing it to maneuvering a motor boat in a moving stream. If the boat had a maximum speed of 10 mph and the stream was flowing at 10 mph, for example, the boat could face upstream at full throttle and remain in place in relation to the bank. If the boat turned downstream at full throttle, it would be moving 20 mph in relation to the bank. If the boat left one bank and kept its bow pointed directly at the other side at full throttle, it would be moving toward the other bank at 10 mph and at the same time be drifting downstream at 10 mph. The boat would reach the other bank at a point downstream equal in distance to the distance of the stream width. For the coxswain to insure that he landed on the desired point of the far bank would require him to launch his boat at a greater distance upstream than the distance of the stream width. He could then land at the desired spot by varying the heading of the boat (crabbing) as needed to fight the effect of the current. A boat with no motor would drift downstream without control and would not reach the far bank.

c. A direct comparison can be made with parachutes. A standard T-10 or other nonsteerable parachute used in a 10 mph wind would drift to the ground at a normal rate of descent plus the lateral speed of 10 mph. The T-10 equipped parachutist would drift approximately 850 feet from the exit point prior to landing on a static-line jump. A free-fall

jumper with the necessity for a higher opening altitude would drift over 2,000 feet from the opening point prior to landing in a nonsteerable T-10 type canopy. A steerable canopy with a forward speed of 10 mph would drift to the ground with the same rate of descent as the T-10 but with a lateral speed of 20 mph if facing with the wind or at 0 mph forward speed if faced into the wind. By utilizing the brakes, the parachutist could control his lateral speed along the windline at any speed from 0 to 20 mph. Facing the wind without brakes would give a 0 mph ground speed. Continuing to face the wind and applying brakes would reduce the ability of the canopy to counter the wind, and it would drift backwards. With full brakes on the canopy, facing the wind would no longer have a forward drive, and it would be blown to the rear at 10 mph as would a T-10. Facing about and running with the wind, the parachute would move at a ground speed of 20 mph. Applying the brakes would reduce the forward speed until full brakes were applied when the forward thrust of the canopy would be terminated and the parachute would be drifting to the front at 10 mph similar to a T-10. In the 10 mph wind described, the parachutist can select a landing point by controlling his ground speed along the wind line from 0 to 20 mph. As the boat coxswain would launch his boat at a greater distance upstream than the distance of the stream width, the parachutist's jumpmaster would select an exit point somewhat upwind from the desired landing point. Having the capability to fight the wind and descent at 0 mph ground speed, turn and run with the wind at up to

20 mph, or crab to positions to one side or the other of the windline makes a precise landing in a designated spot very easy.

d. By turning the parachute into the 10 mph wind just prior to landing and not applying the brakes gives the parachutist a gentle landing with 0 mph lateral movement. This is important since most injuries incurred in landing are a result of the lateral movement rather than the vertical rate of descent. A parachutist with a T-10 hits the ground with the impact resulting from his rate of descent of approximately 18-20 feet per second plus the force of the additional lateral movement of 15 mph. A parachutist jumping the MC1-1 for example, would face into the wind and land with the same rate of descent as the T-10 but with a lateral movement of only three to five mph. A jumper would experience the same impact upon landing by using a T-10 in a 15 mph wind as he would by using an MC1-1 in a 25 to 27 mph wind.

APPENDIX B

Canopy Configuration and Operational Characteristics[5]

1. <u>Modified 28 foot circular canopies</u>

a. The 28 foot circular canopy has two basic designs. One configuration is the 1.6 ounce low porosity (30-50 CFM). The other is the standard porosity (90-120 CFM) 1.1 ounce ripstop nylon. Both are equipped with control lines for maneuvering purposes. The rate of descent of the 28-foot canopy is excessive except for the low porosity double "L" design. It has been reported that the 28-foot double "L" also has an excessive rate of descent when full military equipment is worn and carried by the parachutist. The forward speed and turning time are as follows:

Type canopy	Speed	Turning time
28 foot double "L"	8 MPH	3-5 seconds

b. Steerability is rated good in the case of the low porosity "TU" to unsatisfactory for the standard porosity "T" with Derry Slots. The rate of descent appears to be excessive in all of the 28-foot canopies tested to date.

2. <u>Modified T-10 canopies</u>

a. The T-10 canopy is a 35-foot diameter, extended-shirt circular canopy made from 1.1 ounce, green ripstop

---

[5]Appendix B is the authors' summary of each parachute canopy configuration under consideration based on reading the material referenced in the bibliography pertaining to each parachute.

nylon parachute cloth. This canopy can be modified to conform to the MC1 canopy. This modification consists of removing material from the rear of the canopy and attaching a left and a right control line, except in the case of the MC1 (HALO configuration). The MC1 is maneuvered by use of slip risers. The rate of descent does not exceed the 18-20 feet per second descent of the standard T-10 for any of the modifications shown below. The forward speed and time required for a 360-degree turn is as follows:

Type Canopy	Speed	Turning Time
MC1 (HALO) (w/control lines)	4-6 MPH	8-10 seconds
MC1 (HALO) (w/Slip Riser)	4-6 MPH	17-20 seconds
Double L	approx 6 MPH	5-8 seconds
Double Gary Gore	approx 6 MPH	5-8 seconds
5-gore "TU"	8-10 MPH	5-8 seconds
7-gore "TU"	10-12 MPH	5-8 seconds

b. The rate of descent of all of the modified T-10 canopies is considered to be equivalent to the unmodified or standard T-10 canopy. Steerability is considered good to outstanding with the 7-gore "TU" being considered the best because of the higher forward speed. Also considered to be of major importance is the stability of this canopy while making turns. Oscillation is almost nonexistent which permits steering corrections to be made all the way down to the point of impact. Forward speeds range from 10 to 12 mph maximum to varying lesser speeds when being braked down to

a 0 mph forward speed at full brakes. This canopy may be braked to 0 mph forward speed without loss of stability or control. Errors in judgment on the part of the parachutist often result in a somewhat different touchdown point than that which was intended, but do not pose the potential problem found in jumping the high-performance canopies, which can result in stalls and loss of control for a resultant hard and dangerous landing velocity and attitude. The 7-gore "TU" modified canopy has been well exercised and evaluated in the sport parachutist environment where it was the undisputed champion of accuracy prior to the development of the multi-slotted parachutes with aerodynamic lifting qualities. A number of world records for accuracy have been established with this canopy, and it is still considered to be the best competition model in the ciruclar canopy with material removed category. The superb maneuverability is not degraded by the addition of loads up to an including 110 pounds of military equipment. The 7-gore "TU" (MC1-1 and NSP-1/2) is considered to be the best design for general Marine Corps wide use by a very large margin.

3. <u>The MC3 military free-fall parachute system</u>

a. Main Canopy. The main canopy is the MC3, 24-foot diameter main parachute canopy constructed of approximately 2.0 ounces per square yard type-1 ripstop nylon canopy cloth. Twenty-four 550 pound break strength nylon suspension lines extend from the canopy skirt to four connector links mounted on four risers. A control line with a toggle attached to the lower end is secured to the inner side of each of the

two front risers. The upper ends of the control lines are connected to the steering vanes located on opposite sides of the canopy. The control lines are used by the parachutist to induce and control the rate and direction of turns made during descent. Two 1,500 pound break strength tubular nylon lines are attached to connector links which are mounted on the two rear risers. These two lines extend upward and are joined to form the center line which is attached to the apex of the canopy. The canopy is pilot chute/launching sleeve deployed upon actuation of either the manual ripcord or the automatic ripcord release. The canopy has turn slots and vent slots in addition to the stabilizer panels.

b. Automatic Ripcord Release. The automatic ripcord release is the FF-2 automatic parachute release (Type D/1 MK 2). The FF-2 automatic ripcord release has a combined aneroid and timing mechanism. The aneroid scale is calibrated in millibars: the range of the scale corresponds to 200 feet below sea level to 15,000 feet above sea level. A special slide rule allows the parachutists to determine the setting on the automatic ripcord release for the desired altitude it is to function. To use the slide rule, the parachutist must know either the altitude of the drop zone and the pressure altitude at the drop altitude, or the pressure altitude of the drop zone. The FF-2 automatic ripcord release is designed for no-load actuation and requires Bell-jar calibration only after 50 uses.

c. Harness and Packtray. The harness and packtray are the same as that in the present HALO parachute system except for relatively minor design changes. Harness changes consist of providing a new ripcord pocket on the right main lift web of the harness to accept a D-handle ripcord assembly designed to improve the ease of activation of the parachute. The quick-fit ejector snaps have been removed from the leg straps and replaced by quick-fit V-rings. Nonadjustable ejector snaps have been installed at the hip area of the main sling designed to improve the ease of connecting and disconnecting the leg straps. The oxygen mask-to-regulator is located to the left of the main lift web of the harness and the connector inlet is located to face outboard, to the left. With regard to packtray, darts have been removed from the side flaps to allow for the additional volume required for the deployment sleeve. The suspension line and connector link protector flat and quarter deployment bag stabilization tie loops have been removed as they are no longer required. The standard waistband has been removed and replaced by an adjustable waist belt which has ejector snap connectors. The new waist belt is designed to provide ease of attachment and improved restraint of the reserve parachute.

d. Breathing Oxygen Assembly. The breathing oxygen assembly consists of an oxygen mask, oxygen mask-to-regulator, and an oxygen cylinder assembly. The oxygen bottle assembly consists of two oxygen cylinders and a manifold with a standard pressure guage to indicate the readiness for use of the oxygen and an oxygen on-off valve. The oxygen bottle

assembly has a refill capability. The oxygen mask is the same as that in the present HALO parachute system except for a new attachment fixture for the attachment of the oxygen mask to the free-fall helmet. This attachment feature is designed to provide an adequate quick-release capability in the event of an oxygen system malfunction during the free-fall requiring the parachutist to immediately remove the oxygen mask. The attachment feature is also designed to permit removal of the oxygen mask completely from the free-fall helmet when conducting operations not requiring oxygen.

e. Instrument Assembly. The instrument assembly consists of a new low-profile mounting bracket; a night-light with battery, associated wiring, and an on-off switch; and a North Star altimeter calibrated in thousands of feet. The instrument assembly is attached to the top side of the reserve parachute pack.

f. Free-Fall Helmet. The free-fall helmet is the same as that in the present HALO parachute system except for a new attachment feature for the attachment of the oxygen mask to the free-fall helmet. The jumpmaster's free-fall helmet also includes earphones and microphone suitable for use with oxygen mask in order to provide an intercom capability inside the aircraft between the jumpmaster and the aircraft crew.

g. Goggles. The goggles are the same as that in the present HALO parachute system except for a new retention strap designed to prevent loss of the goggles during free-fall operations.

h. Gloves. The gloves are the same as that in the present HALO parachute system.

i. Rear mounted Rucksack Harness. The rear mounted rucksack harness is the same as that used with the present HALO parachute system.

j. Additional statistics:

Type Canopy	Speed	Turning Time	Descent Rate
MC3	14 MPH	3-4 seconds	15 FPS
	braking		30 FPS

k. The Para-Commander has been evaluated and found to be outstanding for steerability and accuracy when loads are not carried. The Para-Commander is the most used parachute in the sport parachuting community. A longer training period is required to master this very responsive canopy as compared to the NSP-1. Although this is not a high-glide ratio canopy, it will stall, which almost doubles the normal rate of descent. Turning too fast or turning downwind when near the ground frequently results in minor injury to the parachutist. Parachutists at the Naval Special Warfare Group Two are required to have 20 to 25 jumps on the NSP-2 or similar parachute before being allowed to jump the Para-Commander.

4. Parawing

a. The parawing has a triangular-shaped canopy with a 254 square foot surface area. It is constructed of 2.25 ounce ripstop nylon with a acrylic coating to make the fabric non-porous. It is saidto fly rather than descend due to its

high rate of forward speed and airfoil configuration. Right and left control lines provide for turning in either direction and for braking.

Type Canopy	Speed	Turning Time	Descent Rate
Parawing	20 MPH	3-4 seconds	14 FPS

b. The Parawing has the lowest performance of the high-glide ratio designs, yet requires the same concern and correct handling to insure that it does not stall. It was evaluated as being too difficult for the average parachutist who has not had special training. Since it only has a glide ration of 2:1, it can be discounted for offset delivery.

5. Parafoil

a. The parafoil is a rectangular-shaped single-chambered airfoil canopy resembling airplane wings. Two types are in existence today. One type has a surface area of 200 square feet with an aspect ratio of 2:0. (The distance from wing tip to wing tip is two times the distance from the leading edge to the trailing edge.) The other parafoil has a surface area of 300 feet with an aspect ratio of 3:0. The parafoil has been described as, "an aircraft or glider which can be packed and deployed like a parachute." This non-rigid wing is divided into cells with openings at the leading edges which permit ram air to enter and inflate the cells. This ram of air together with the negative and reduced pressures over the top surface gives the Parafoil structural rigidity during flight and provides lift. The canopy is constructed of 1.9 ounce ripstop nylon which is

plastic coated to make it nonporous. The Parafoil is controlled with a right and left control line for turning and braking. As brakes are applied the trailing edges are deflected similar to the action of flaps on an airplane. In addition to slowing the forward speed braking increases the rate of descent. At full brakes, but not yet stalled, the rate of descent is almost doubled. The high forward speed when gliding at full speed and the high rate of descent when forward speed is reduced by braking requires special landing techniques in order to avoid injury. Combined velocities of descent and forward movement may reach 40 feet per second or more. The parafoil currently being jumped by the Marine Corps Development Center, Quantico, Virginia, is being jumped on deployed free-falls with openings at terminal velocity (120 MPH) without difficulty. The glide angle (lift over drag) of the large Parafoil appears to be approximately 6:1. Turning time and speeds are as follows:

Type Canopy	Speed	Turning Time	Descent Rate
Parawing	20 MPH	8-10 seconds	10-15 FPS

b. 200 Square Foot Parafoil. These small parafoils are really "hot" as compared to the other designs. They are fast in flight, spiral dive at tremendous speeds, and when handled forcefully fling the parachutist out to a level almost horizontal to the canopy on turns and dives. Timing is critical in landing or else ground speed is excessive or the "flare" landing becomes a stall a few feet off the ground.

It is somewhat unstable in flight having a tendency to slip from one side to the other for no apparent reason. It bounces and surges for a similar unexplained reason. The range of the controls between full flight and the stall state is shorter than in the Para-Plane which makes it more difficult to control than the Para-Plane. The most desirable position for the control line toggles to be in for the stall is with the arms fully extended downward. On a number of jumps, the Para-foil has stalled with the toggles a little more than half way down. This was the most difficult to fly (jump) of all of the designs.

c. 300 Square Foot Parafoil. This unit was just recently acquired and consequently was rather hastily evaluated with a few jumps. The initial impressions have all been very good. It appears to be the best gliding of all of the designs with a glide ratio of approximately 6:1. The rate of descent is lower than the other designs making the landings very gentle and easy to control. The training time required to attain proficiency will be much less on this parafoil than any of the other designs perhaps only requiring half as many jumps as the small model. The lower rate of descent aids in jumping full combat equipment loads. This design appears to offer the most potential for offset delivery of parachutists.

6. <u>Para-Plane</u>

a. The para-plane is a multi-celled flexible glider with upper and lower surfaces inflated by ram air into an airfoil configuration. The glider parachutes with double

envelopes have high aerodynamic qualities for small areas of load-bearing surface. The para-plane (commonly called "cloud" competition Para-Plane) has a surface area of 240 square feet. The Para-Plane is constructed of 1.5 ounce calendered and treated ripstop nylon. The canopy is made of nylon cloth with zero air penetrability. The area of the lower surface is $15m^2$, the upper $18m^2$. The Para-Plane is rated by the manufacturer as having the following speeds:

Type Canopy	Speed	Rate of Descent
Para plane	20-30 MPH	14-18 FPS

b. The manual shows the rate of descent increasing to 22 FPS and when slotted a descent rate of 25 FPS. The glide ratio is 3:1.

c. The Para-Plane has proven to be the easiest to handle design of any of the high glide ratio parachutes. It is reported to be stable in flight with no side slipping or unexpected surging [Ref. 22].

d. Control of the canopy is done using 2 shroud lines attached to the rear edge of the canopy, and 2 tightening tapes for changing the angle of attack of the canopy, attached to the forward free ends of the harness system. For providing reliability of operation of the canopy and decreased dynamic stress at the moment of filling, a reefing device is used on the upper lifting surface; it consists of two cords passed through rings attached to the surface of the canopy. Two pilot parachutes with conical springs are attached to the reefing cord.

7. <u>The MC1-2 military free-fall parachute system</u>

a. The modified MC1-2 is a modified altitude low-opening parachute assembly which was designed to replace the MC1-1.

b. The modified parachute assembly is intended for use by combat troops to deploy into a hostile environment from a high altitude and then free fall to a low altitude prior to opening the parachute. The MC1-2 has a more maneuverable canopy than the MC1, larger pilot chute and is packed in a sleeve. The F-1B automatic timer is used in the assembly as a safety device to automatically open the canopy at a preselected height above the ground in the event the jumper fails to pull the ripcord.

c. The modified HALO exceeds the required .90 reliability and .90 per cent confidence level of operation.

d. Main canopy. The main canopy is a MC1-2 canopy which has the configuration, including control lines, as the standard MC1-1 static line deployed maneuverable parachute except it is pilot chute/launching sleeve deployed upon actuation of either the manual ripcord or the automatic ripcord release. Basically, the canopy is a 35 foot nominal diameter, nylon canopy that has been modified with a 7-gore "TU" modification. The canopy is capable of providing 18.9 feet per second forward speed.

e. Sleeve. The sleeve is nonstandard--must be purchased commercially or procured as part of the total assembly.

f. Pilot Chute. The pilot chute is a standard 36-inch chute launched deployable sleeve deployed upon actuation of either the manual ripcord or the automatic ripcord release.

g. Other Components. All other components of the MC1-2 Military Free-Fall Parachute System are the same as described above in paragraphs 3. a through i.

h. The following speeds and turn times are provided:

Type Canopy	Speed	Turning Time
MC1-2	18.9 FPS	9.8-10.2 seconds

8. HALO

a. Canopy. The personnel back parachute (HALO) has a 35-foot diameter nominal parabolic circular canopy, a pack assembly, a harness assembly, two user assemblies and a vane type pilot chute. The 35-foot nominal diameter, nylon canopy that has been modified with a 7-gore "TU" modification. This modification makes the canopy steerable by giving it an approximate 8-knot forward speed. It also contains control lines and toggles which the jumper can pull down to rotate the canopy for directional steering.

b. Sleeve. The sleeve is a nonstandard, commercially manufactured cotton twill encasing for the canopy and for the stowing suspension lines. The purpose of the sleeve is to insure that the canopy is fully elongated and the suspension lines fully deployed prior to the start of canopy inflation. This greatly reduces the opening force on the parachute.

c. Retainer Line. This line insures that the pilot chute and sleeve are retained with the parachute assembly after inflation of the main canopy. It is locally manufactured from 16 feet of 1,000-pound tensile strength tubular nylon.

d. Other Components. All other components of the HALO parachute system are the same as described above in paragraphs 3.a through i.

9. Tab 1 is a summation of parachute canopies being tested by the U. S. Naval Aerospace Facility, El Centro, California, but not evaluated in this analysis. The information provided is not complete and appears herein for informational purposes only.

Tab 1

Gliding Parachutes Under Experimentation

The U. S. Navy has been investigating the feasibility and potential use of various configurations of maneuverable personnel gliding parachute assemblies for employment in predetermined parachute operations. The available data to date concerning the results of each configuration appears below. (All tests were non-live tests.)

a. Sailwing [Ref. 23]

(1) Aspect ratio of four and a planform area of 400 square feet.

(2) 18 torso dummy drops were conducted by NAVERORECOVFAC, El Centro, with weights of 200, 250, and 300 pounds.

(3) Launch speeds - 60, 80, and 110 KIAS.

(4) Canopy size - 30 feet.

(5) Weight - 34 pounds.

(6) Volume 2.1 cubic feet.

(7) Components of assembly-canopy, deployment bag, parachute container, pilot chute, and reefing line cutters.

(a) Canopy configuration - five-lobed canopy rectangular in shape, with an airfoil type leading edge.

(b) Suspension lines - 36 lines attached to the cantenary panels sewn to the canopy.

(c) Material - 1.6 ounce per square yard ripstop nylon cloth, coated to reduce permeability.

(8) Test results - normal deployment for 7 of 18 tests. Eleven of the tests either damage was incurred, or because of a malfunction, the canopy failed to reach a full open state prior to impact.

(a) Rate of descent/horizontal velocity/lift to drag ratio

Type A/C	Gross Weight	Altitude	KIAS	Rate of Descent	Hor Vol	L/D
C47	200 lbs.	1500	110	5.43	12.3	2.3
C47	250 lbs.	1500	110	7.67	25.16	3.28
C47	300 lbs.	1500	110	9.18 (average)	29.7 (average)	2.93
U6A	300 lbs.	1500	60	9.85	31.14	3.16
H21	300 lbs.	1500	60	9.76	25.05	2.56
C47	300 lbs.	1500	80	21.3	23.01	1.62
C47	300 lbs.	1500	110	10.6	30.16	3.01

(9) Conclusion - tests indicated that the sailwing gliding parachute assembly, when deployment is satisfactory, descends in a very stable manner with little or no oscillation.

b. 22.5 foot, single-keel, slotted parawing maneuverable, personnel gliding assembly [Ref. 24]

(1) Planform area - 400 square feet.

(2) A total of 66 torso dummy drops were conducted by the U. S. Naval Aerospace Recovery Facility, El Centro, utilizing gross weights of 200, 250, and 300 pounds.

(3) Launch speeds - 60 to 250 KIAS.

(4) Canopy - 39 pounds.

(5) Weight - 39 pounds.

(6) Volume - 1.8 cubic feet.

(7) Components and assembly. Canopy assembly and deployment sleeve.

(a) Canopy configuration closely resembles an "Eagle Parawing" which is constructed with a flat pattern sweep angle of 45 degrees and the nose cut off aft of the theoretical leading edge of the apex.

(b) Suspension lines are attached to cord loops that are located on the canopy at the two leading edges and the keel. The suspension lines consist of 12 leading edge lines and seven keel lines.

(c) Materials. The canopy is fabricated from calendered 2.25 ounce per square yard ripstop nylon cloth permeated with silicone to reduce permeability.

(8) Test results - there was normal deployment and openings of the parawing in 64 of 66 tests. All parawings which sustained minor damage still had an acceptable rate of descent.

(a) Rate of descent/horizontal velocity/lift to drag ratio

Type A/C	Gross Weight	Altitude	KIAS	Rate of Descent	Hor Vol	L/D
U6A	300	1500	70	12.71	23.33	1.84
U6A	300	1500	80	12.33	23.26	1.88
C47	200	1500	110	10.5	24.52	3.23
C47	250	1500	110	10.9	17.23	1.58
C47	300	1500	110	12.7	22.67	1.80

(9) Conclusion - the tests indicated that this configuration of gliding parachute assembly is very stable during descent with little oscillation.

c. Twin Catenary Keel Parawing Maneuverable Personnel Gliding Parachute Assembly [Ref. 25].

(1) Planform area for the 16 foot keel length twin catenary parawing is 270 square feet.

(2) Fifty-four torso dummy drops weighing 200, 250 and 300 pounds were conducted by NAVAERORECOVFAC at altitudes from 1500 to 15,000 feet.

(3) Launch speeds - 60 to 300 KIAS.

(4) Canopy size - 16 feet.

(5) Canopy weight - 39 pounds.

(6) Volume - 1.3 cubic feet.

(7) Components and assembly - canopy assembly deployment bag, a 40-inch diameter Pioneer pilot parachute, parachute container and harness.

(a) Canopy configuration - the twin catenary keel parawing consists of a three-lobed canopy with two catenary keel panels which are parabolic in shape.

(b) The 24 suspension lines are attached to webbing loops that are located on the canopy at the two leading edges of the two keels.

(c) Material - the canopy is fabricated from calendered 2.9 ounce per square yard ripstop nylon cloth with polyurethane to reduce permeability.

(8) Test Results - normal deployment and opening of the canopy in 51 of 54 tests.

(a) Rate of Descent/Horizontal Velocity/Lift to Drag Ratio:

Type A/C	Gross Weight	Altitude	KIAS	Rate of Descent	Hor Vol	L/D
UIB	200	1500	110	10.88	21.42	2.08
C130	200	1500	110	11.03	20.51	1.91
U1B	250	1500	110	11.98	23.67	1.98
C130	250	1500	110	10.29	28.80	2.77
U1B	300	1500	110	13.73	26.89	2.04
C130	300	1500	110	11.19	31.21	2.19

(9) Conclusion - The tests indicated that the configuration of the gliding parachute assembly was very stable during descent with little or no oscillation.

d. Para-Foil [Ref. 26]

(1) Aspect ratio 2 and a planform area of 360 square feet.

(2) Thirty-three torso dummy drops were conducted by NAVAERORECFAC. Gross weight of the torso dummies were 200, 250, and 300 pounds.

(3) Launch speeds - 110 and 131 KIAS.

(4) Canopy - rectangular in shape with a single camber air foil profile - 1.9 ounce per square yard ripstop nylon.

(5) Weight - 48 pounds.

(6) Volume - 3.2 cubic feet.

(7) Components - canopy - single camber profile type.

(a) Canopy - non-rigid, air foil, divided into cells with openings at the leading edge. These inlets provide air to be rammed into the leading edges.

(b) Suspension lines - thirty-six lines constructed of 750 pound tensile strength nylon cord. Eight control lines, four on each side of trailing edge of para-foil and extended to two confluent points.

(c) Deployment sleeve - constructed of 4 ounce per square yard vat-dyed cotton cloth.

(8) Test results - normal deployment and opening of para-foil in 25 of the 33 tests.

(a) Rate of Descent/Horizontal Velocity/Lift to Drag Ratio

Type A/C	Gross Weight	Altitude	KIAS	Rate of Descent	Hor Vol	L/D
U1B	200	1500	110	8.63	27.31	3.15
U1B	250	1500	110	9.45	30.17	3.19
U1B	300	1500	110	10.56	30.23	2.88
U1B	300	1500	60	10.48	41.05	3.89
C47	300	1500	80	10.65	33.7	3.07
C47	300	1500	110	11.25	37.84	3.39
B66	300	1500	150	12.17	39.77	3.76
B66	300	1500	175	41.68	25.99	.91

(9) Conclusions - continue further investigation and tests of para-foil concept.

APPENDIX C

Delivery Flexibility

Purpose. To determine the flexibility of deployment of the parachute being analyzed commensurate with the capabilities of Naval Aircraft.

General Discussion. Tactical insertion of small unit parachute teams must be accomplished as dictated by the situation. The team's mission, the location and capabilities of the enemy, terrain, and weather are all key factors. Accordingly, the success or failure of the insertion of the team is dependent upon the insertion method. High altitude and/or high speed deployment of parachutists is desired to reduce detection of aircraft, and reduce vulnerability of aircraft to ground fire. Also, high altitude deployment normally allows the aircraft to increase its distance from the jumper's landing site (i.e., reduces the possibility of the enemy detecting jumpers and/or determining where the jumpers may land). Conversely, low altitude deployment may be advantageous in order to penetrate beneath the horizon capabilities of the enemy's radar net or to fly beneath a low ceiling weather front. Low speed deployment may be necessary for safety purposes particularly when flying at low altitudes; also, low speed deployment may help reduce dispersion among jumpers. The more flexible the parachute systems, the more options available to both the parachute team and aircraft commander in choosing the preferable

insertion method. Parachute versatility is meaningless, however, unless suitable Naval aircraft are available for parachute operations and capable of providing a matching versatility.

Method. The flexibility score is derived by matching each parachute with Naval aircraft capabilities at selected altitudes and velocities. When both the parachute and the aircraft are able to perform at the specific altitude or velocity, an "X" will be placed in the corresponding flexibility grid square (see Tab 1 to this appendix). Total "X" markings will be tabulated for each parachute--one total will be obtained for carrier landing/takeoff qualified aircraft and the other total for all aircraft considered. The score attained by the MC1-1 is the base score, and will be "normalized" as 100. The following formula will be used to compute the Flexibility Score for the jth parachute:

$$F'_j = \frac{F_j}{F_{base}} \times 100 \qquad (16)$$

where F_j is the flexibility raw score for the jth parachute, F'_j is the Flexibility Score for the jth parachute, and F_{base} is the flexibility raw score for the base parachute MC1-1. Flexibility scores are computed and appear in Table C-1.

Parachute. Most parachute versatility data was derived implicitly from the jump data on each parachute. The test jumps of record (either with dummies or personnel) normally

covered the complete range of altitudes and velocities used in this flexibility analysis. If adverse findings are not specified in the studies, the assumption is made that the parachute performed satisfactorily.

Test jump data for the MC3 and 28' Flat canopies at low altitudes is not available. On the basis of "general descriptive performance capabilities" gleaned from the studies conducted at the National Parachute Test Range and specific findings of the Final Report of Steerable Parachutes (Project 20-69-10) [Ref. 27] prepared at the Marine Corps Development and Education Command, the MC3 and 28' Flat canopies will be treated as capable of being jumped at low altitudes (i.e., 1,250 feet) in this analysis. Two caveats are appropriate in the cases of these two canopies. First, there is a paucity of information concerning actual resutls of low altitude deployment of these two canopies. Second, the information available indicates that these two canopies, as well as the other steerable parachutes being considered, leave little margin for parachutist's error when jumped at low altitudes.

Jump data on the Para-Foil [Ref. 26], reveals that when the canopy was opened while jumping from aircraft traveling in excess of 150 KIAS, opening shock and canopy damage were significant in magnitude and extent. The opening shock was over 4,000 pounds--almost three times as much as most of the other steerable parachutes. Although this degree of opening shock is not prima facie a disqualifying attribute, it has serious implications. Irrefutably, the greater the opening shock, the greater the possibility of upper torso injury to

the parachutist. An experienced parachutist, when queried upon his reaction to a 4,000 pound shock, responded with, "OUCH!" [Ref. 27]. To be even more definitive, studies conducted by the National Parachute Test Range found a direct relationship between the opening shock and the high incidence of canopy damage when test deploying the Para-Foil in excess of 150 KIAS. Over one half of the jumps made (all with dummies) resulted in canopy damage ranging from minor to major. On the basis of the foregoing, the Para-Foil will be treated as not being capable of deployment at velocities over 150 KIAS. If this decision appears to bias the overall analytical evaluation, then the Para-foil will be treated as capable of deployment at velocities in excess of 150 KIAS in the sensitivity analysis.

Aircraft. The aircraft considered are limited to those available to the Naval service (Navy and Marine Corps) which could be utilized in a tactical situation.

Basic aircraft considerations are:

1. Ability to transport at least four fully equipped parachutists up to 250 miles to the drop zone and then return to base/carrier (500 mile round trip).

2. Compatibility of bulk of parachutist and equipment with exit door/hatch conditions.

3. Suitable aircraft configuration (fuselage appendages (e.g., antennae), exit door/ramp conditions, etc.) to allow an unimpeded jump.

4. No aerodynamic characteristics which would cause entanglement of the parachute with the aircraft's empennage or fuselage appendages, or would cause the parachutist to come into contact with the aircraft.

5. Additionally, those aircraft capable of carrying out sea-based (carrier) flight operations are identified.

During 1972, the National Parachute Test Range conducted a study for the Naval Air Systems Command [Ref. 18]. The study addressed the suitability of Naval aircraft for premeditated parachute operations. This analysis will not include all aircraft considered by the study, but will include all aircraft which would reasonably be expected to be available for parachute operations in the U. S. Marine Corps' tactical environment. Reference 18 greatly facilitated the accumulation of aircraft versatility data since the study matched type of aircraft with type(s) of parachute jumps. Supplementary data was obtained by interviews with Major Andrew "Ben" Adams, United States Marine Corps, Aeronautical Engineering, Air Safety Program, Naval Postgraduate School, Monterey, California.

The interviews with Major Adams revealed two significant points. One, although the National Parachute Test Range study certified the UH1M, CH-46, and CH-53 helicopters for both static line and free fall jumps, free fall jumps are <u>definitely</u> preferred. The static lines used in a static line jump can easily "foul" with helicopter equipment (e.g., tail ramp on the CH-53), engines, and/or rotars. This in itself is not enough to disqualify these helicopters from

conducting static-line operations; however, it is a hazard which must be considered in selecting the mode of aircraft exit/type of parachute. The other significant point is that the UH1M helicopter may not be able to meet the distance requirement of the 500 mile trip. Weather, weight, altitude, temperature, and speed are all critical; nevertheless, the UH1M can be configured with additional fuel cells which may, depending on the degree of influence of the aforementioned constraints, overcome this deficiency.

Parameters

1. Velocity. The term "velocity" as used in this flexibility analysis is the speed of the aircraft in KIAS at the moment the parachutist exits the aircraft. 150 KIAS was selected as the critical velocity because all studies reviewed indicated or implied that this velocity was the dividing point between low and high velocity jumps. Perusal of the jump data revealed that those parachutes capable of being utilized for jumps at velocities in excess of 150 KIAS could be safely used at velocities noticeably in excess of 150 KIAS (i.e., 160-200 KIAS. The MC3 had the top rating of 200 KIAS).

2. Altitude. Altitude must be considered in two different frames of reference--altitude above sea level (known in aviation jargon as MSL) and altitude above ground level (AGL).

a. 1,250 feet AGL is used as the low altitude parameter since this is the minimum static-line jump altitude

presently authorized by the Marine Corps. This altitude allows a parachutist time and distance necessary to deploy his reserve parachute in case of a malfunction of his main parachute.

b. 10,000 feet MSL is used as the mid-range altitude parameter. This altitude can reasonably be considered high enough to allow low level AGL jumps above almost all ground levels encountered in an amphibious operation. This altitude also places the aircraft out of the effective range of small arms fire in most cases, and places the aircraft out of the effective range of weapons up to 50 caliber located at ground levels up to 5,000 feet. Additionally, 10,000 feet MSL is critical since it is the maximum altitude that can be attained by aircraft before provisions for oxygen must be made for both crew and passengers.

c. 22,500 feet MSL is the upper range limit being considered because it is sufficiently high enough to attain the benefits of high altitude jumping. It is also, physiologically, the maximum altitude that a parachutist can jump without carrying oxygen apparatus.

Computation. Tab 1 to this appendix provides the data for determination of the flexibility raw scores.

FLEXIBILITY SCORES				
Parachute	CC* Raw Score	Total Raw Score	CC* Flexibility Score	Flexibility Score
MC1-1	18	24	100	100
T-10	18	24	100	100
MC1	18	24	100	100
MC3	23	36	128	150
28' Flat	23	36	128	150
Para-Plane	17	27	94	113
Para-Foil	14	23	78	96
Para-Wing	23	36	128	150
Strato-Star	17	27	94	113
Strato-Cloud	17	27	94	113

Table C-1

*Carrier qualified aircraft only

T-10 PARACHUTE — Tab 1 — 18 C.C. SCORE — 24 TOTAL SCORE

	AIRCRAFT (* carrier capability)	* UH1M	* CH-46	* CH-53	* OV-10	* C-130	* C-2A	A-3	C-1A	C-117
VELOCITY	OVER 150 KIAS									
VELOCITY	UNDER 150 KIAS	X	X	X	X	X	X		X	X
ALTITUDE	22,500 FT. MSL									
ALTITUDE	10,000 FT. MSL	X	X	X	X	X	X		X	X
ALTITUDE	1,250 FT. AGL	X	X	X	X	X	X		X	X

MC-1 PARACHUTE — 18 C.C. SCORE — 24 TOTAL SCORE

	AIRCRAFT (* carrier capability)	* UH1M	* CH-46	* CH-53	* OV-10	* C-130	* C-2A	A-3	C-1A	C-117
VELOCITY	OVER 150 KIAS									
VELOCITY	UNDER 150 KIAS	X	X	X	X	X	X		X	X
ALTITUDE	22,500 FT. MSL									
ALTITUDE	10,000 FT. MSL	X	X	X	X	X	X		X	X
ALTITUDE	1,250 FT. AGL	X	X	X	X	X	X		X	X

MC1-1

PARACHUTE — C.C. SCORE: 18 — TOTAL SCORE: 24

		* UH1M	* CH -46	* CH -53	* OV-10	* C-130	* C-2A	A-3	C-1A	C-117
VELOCITY	OVER 150 KIAS									
	UNDER 150 KIAS	X	X	X	X	X	X		X	X
ALTITUDE	22,500 FT. MSL									
	10,000 FT. MSL	X	X	X	X	X	X		X	X
	1.250 FT. AGL	X	X	X	X	X	X		X	X

AIRCRAFT

* carrier capability

MC-3

PARACHUTE — C.C. SCORE: 23 — TOTAL SCORE: 36

		* UH1M	* CH-46	* CH-53	* OV - 10	* C-130	* C-2A	A-3	C-1A	C-117
VELOCITY	OVER 150 KIAS				X	X	X	X	X	
	UNDER 150 KIAS	X	X	X	X	X	X	X	X	X
ALTITUDE	22,500 FT. MSL					X	X	X		X
	10,000 FT. MSL	X	X	X	X	X	X	X	X	X
	1,250 FT. AGL	X	X	X	X	X	X	X	X	X

AIRCRAFT

* carrier capability

28' FLAT PARACHUTE — C.C. SCORE: 23 — TOTAL SCORE: 36

VELOCITY	OVER 150 KIAS				X	X	X	X	X	
	UNDER 150 KIAS	X	X	X	X	X	X	X	X	X
ALTITUDE	22,500 FT. MSL					X	X	X		X
	10,000 FT. MSL	X	X	X	X	X	X	X	X	X
	1.250 FT. AGL	X	X	X	X	X	X	X	X	X
AIRCRAFT * carrier capability		* UH1M	* CH -46	* CH -53	* OV-10	* C-130	* C-2A	A-3	C-1A	C-117

PARA-PLANE PARACHUTE — C.C. SCORE: 17 — TOTAL SCORE: 27

VELOCITY	OVER 150 KIAS				X	X	X	X	X	
	UNDER 150 KIAS	X	X	X	X	X	X	X	X	X
ALTITUDE	22,500 FT. MSL					X	X	X		X
	10,000 FT. MSL	X	X	X	X	X	X	X	X	X
	1,250 FT. AGL									
AIRCRAFT * carrier capability		* UH1M	* CH-46	* CH-53	* OV-10	* C-130	* C-2A	A-3	C-1A	C-117

PARA-FOIL PARACHUTE

14 C.C. SCORE

23 TOTAL SCORE

		* UH1M	* CH -46	* CH -53	* OV-10	* C-130	* C-2A	A-3	C-1A	C-117
VELOCITY	OVER 150 KIAS									
	UNDER 150 KIAS	X	X	X	X	X	X	X	X	X
ALTITUDE	22,500 FT. MSL					X	X	X		X
	10,000 FT. MSL	X	X	X	X	X	X	X	X	X
	1.250 FT. AGL									

AIRCRAFT

* carrier capability

PARA-WING PARACHUTE

23 C.C. SCORE

36 TOTAL SCORE

		* UH1M	* CH-46	* CH-53	* OV -10	* C-130	* C-2A	A-3	C-1A	C-117
VELOCITY	OVER 150 KIAS				X	X	X	X	X	
	UNDER 150 KIAS	X	X	X	X	X	X	X	X	X
ALTITUDE	22,500 FT. MSL					X	X	X		X
	10,000 FT. MSL	X	X	X	X	X	X	X	X	X
	1,250 FT. AGL	X	X	X	X	X	X	X	X	X

AIRCRAFT

* carrier capability

STRATO-STAR PARACHUTE

17 C.C. SCORE

27 TOTAL SCORE

		* UH1M	* CH -46	* CH -53	* OV-10	* C-130	* C-2A	A-3	C-1A	C-117
VELOCITY	OVER 150 KIAS				X	X	X	X	X	
	UNDER 150 KIAS	X	X	X	X	X	X	X	X	X
ALTITUDE	22,500 FT. MSL					X	X	X		X
	10,000 FT. MSL	X	X	X	X	X	X	X	X	X
	1.250 FT. AGL									
AIRCRAFT * carrier capability										

STRATO-CLOUD PARACHUTE

17 C.C. SCORE

27 TOTAL SCORE

		* UH1M	* CH-46	* CH-53	* OV-10	* C-130	* C-2A	A-3	C-1A	C-117
VELOCITY	OVER 150 KIAS				X	X	X	X	X	
	UNDER 150 KIAS	X	X	X	X	X	X	X	X	X
ALTITUDE	22,500 FT. MSL					X	X	X		X
	10,000 FT. MSL	X	X	X	X	X	X	X	X	X
	1,250 FT. AGL									
AIRCRAFT * carrier capability										

GLOSSARY

ACE -----------------Airborne Communications and Electronics Board, Fort Bragg, North Carolina.

ADAPTER, HARNESS, QUICK-FIT ---An adapter with the fixed crossbow replaced by a floating friction grip. The adapter is incorporated in a harness web to permit quick adjustment.

AIRBORNE ------------A term applied to personnel and equipment delivery from aircraft.

AIR DROP ------------A method of air movement wherein personnel, supplies, and equipment are unloaded from an aircraft in flight.

APEX ----------------The center and topmost point of a parachute canopy.

AREST ---------------Aerial Rapid Egress System for troops.

AUXILIARY -----------The second chute used in intentional jumps commonly referred to as the emergency or reserve parachute.

BACKSTRAP -----------A part of the harness that extends across the small of the wearer's back. It may or may not be adjustable.

BAG, DEPLOYMENT -----A container, usually of fabric, in which a parachute canopy is stowed for deployment. There may or may not be provision for stowing suspension lines on the bag. Usually, either a static line or pilot chute lifts the deployment bag away or extracts it from a parachute pack or storage container. Normally, with this system the suspension lines are extended before the drag producing surface emerges from the deployment bag.

BRAKE PARACHUTE -----A parachute streamed from an aircraft to reduce its landing run or to steepen its diving angle.

C-130/KC-130F -------The C-130 is a high wing, all metal, long range, land-based monoplane. The mission of the aircraft is to provide inflight refueling or rapid transportation of personnel or cargo for delivery by parachute or landing.

C-47 (DC-3CO)(SKYTRAIN)--A twin engine transport powered by two Pratt and Whitney R 1830-92 twin-wasp fourteen cylinder radial cooled engines. This aircraft is capable of transporting 28 fully equipped airborne or combat troops.

C-117 ---------------This aircraft is capable of transporting 40-42 passengers and is equipped with four 1,000 horsepower Pratt and Whitney R-2000 twin wasp engines.

C1A (TRADER) --------Formerly the TF-1. The C1A Trader is a general utility transport trainer version of the S-2 Tracker. It is capable of carrying nine passengers in backward-facing easy removable seats.

C2A (HAWKEYE) -------Carrier based early warning aircraft capable of remaining aloft for prolonged periods. Capable of carrying 5 passengers.

C-141 (STARLIFTER) --A turbofan powered freighter and troop carrier operated by the United States Air Force Military Airlift Command. The aircraft provides global-range airlift for the Military Airlift Command and Strategic deployment capabilities at jet speeds for the United States Strike Command.

CH-46 (SEA KNIGHT) --A twin engine medium transport helicopter. The rotor consists of two three-blade rotors rotating in opposite directions. Depending on seat arrangements, 33-44 troops can be accomodated in the main cabin.

CH-53 ---------------The CH-53 is the Marine Corps' heavy-lift helicopter, has a lift capacity of 8 tons. The CH-53 carries troops and cargo internally and has the capability to carry additional cargo externally.

CABLE, RIPCORD ------A flexible cable joining the locking pins and the ripcord grip. The ripcord cable usually is of carbon steel or corrosion-resistant flexible steel, normally 3/32 inch in diameter. It consists of seven strands with seven wires per strand.

CANOPY --------------That portion of a parachute consisting of the drag producing surface (fabric area) and the suspension lines extended to a mutual point of confluence.

CANOPY-RELEASE ASSEMBLIES --Devices which allow immediate detachment of the canopy. They connect the harness main lift web straps to the canopy risers.

CARP ----------------Computed Air Release Point.

CHUTE ---------------A contraction of the term parachute and used inter-changeably with it.

CONTAINER -----------That portion of the parachute assembly which holds the canopy in place after being folded. This is not to be confused with the term "pack."

DECELERATE ----------To slow down.

DELAYED DROP --------A live parachute descent when the activation of the parachute is delayed longer than is necessary to clear the aircraft.

DEPLOYMENT ----------That portion of a parachute operation occurring from the initiation of the activation to the instant the suspension lines are extended, but prior to inflation of the canopy.

DEPLOYMENT BAG ------A method of canopy deployment utilizing a container, usually of fabric, for retaining the drag-producing surfaces of the canopy until the suspension lines are deployed. This reduces the snatch force by allowing the acceleration of the canopy mass in small increments only. The lines may or may not be stowed on the bag, depending on the intended use.

DIAMETER, NOMINAL ---The computer diameter designation of any design of parachute canopy, which equals the diameter of a circle having the total area as the total area of the drag-producing surface, which includes all opening in the drag-producing surface, such as slots and vents. Since it refers to all canopies on a common basis, that is, in terms of surface area, this method of diameter designation is preferred for the comparison of drag efficiencies of different canopy designs. For canopies that have a vent area larger than one percent of the total area, the vent area is deducted from the total area (for example the airfoil parachutes). This term is not used for canopies of the glide-surface type (ribbed and ribless).

DRIFT ---------------Horizontal displacement measured on the ground from the point immediately below the parachute when it opens to the point when the load first comes in contact with the ground.

DROP ALTITUDE -------Actual altitude of the aircraft above the ground at the time the personnel are released.

DROP TEST -----------Dropping of a dummy or other load from an aircraft in flight or otherwise simulating a live jump to prove serviceability of a parachute.

DZ ------------------Drop Zone.

ECM -----------------Electronic Counter Measures.

FREE FALL -----------A parachute jump in which the parachute is activated manually by the jumper at his discretion.

FREE-DROP -----------Delivery of supplies and equipment from aircraft in flight without use of parachutes.

FM ------------------Field Manual.

FMFM ----------------Fleet Marine Force Manual.

FPS -----------------Feet Per Second.

FORWARD SPEED -------The rate at which a parachute moves horizontally in a mass of air.

GLIDE ---------------The horizontal movement of the canopy.

HALO ----------------High Altitude Low Opening.

HANDLE, RIPCORD -----A metal loop designed to provide a grip for pulling locking pins from the locking cones of ripcord-actuated parachutes.

HARNESS -------------That component of the parachute assembly which incases the jumper and holds the parachute pack to the jumper.

HARNESS RELEASE -----A manually operated device fixed to one end of the harness webbing and equipped with three prongs to accomodate lugs on free ends of harness webbing; it is designed to permit rapid release of troop type harnesses.

HIGH-VELOCITY DROP --The act or process of delivering supplies or equipment from an aircraft in flight where the rate of descent exceeds that obtained utilizing conventional cargo parachutes and methods, but less than terminal velocity (free fall).

HOUSING, RIPCORD ----A flexible metal tubing in which the ripcord cable is installed. The tubing protects the ripcord cable from snagging and provides a free path for it.

JUMPING ATTITUDE ----Steady, level flight of a troop-carrier at a speed necessary to permit parachutists to make a safe exit.

KIAS ----------------Knots Indicated Air Speed.

L/O -----------------Lift to drag ratio.

LCC -----------------Life Cycle Cost.

LPD -----------------Amphibious Transport Dock. The amphibious transport dock was developed from the dock landing ship (LSD) concept but provides more versatility. The LPD replaces the amphibious cargo ship (LKA) and dock landing ship.

LPH -----------------Amphibious Assault Ship. The amphibious assault ship is constructed specifically to operate helicopters. These ships correspond to the Commando Ships of the Royal Navy except the United States ships do not carry landing craft. Each LPH has the capability of carrying a Marine Battalion Landing Team (BLT), with all equipment.

LIFT ----------------The force perpendicular to drag which helps reduce vertical descent.

LINE, STATIC --------A line, cable or webbing, one end of which is fastened to the pack, canopy or deployment bag, and the other to some part of the launching vehicle. It is used to open a pack or deploy a canopy.

LINE, SUSPENSION ----Cords or webbing of silk, nylon, cotton, or rayon materials which connect the drag surface of the parachute harness.

LIVE DESCENT --------A parachute descent made by a human being.

MAIN PARACHUTE ------The primary parachute of a dual assembly.

MALFUNCTION ---------Any discrepancy in the deployment or inflation of the canopy which will increase in the jumpers rate of descent.

OPENING SHOCK -------The decelerating force exerted on the load following that of snatch force. Caused by acceleration of the canopy and the air mass associated with it.

OSCILLATION ---------Pendulum like swinging of the suspended load beneath the inflated canopy. Usually, the result of trapped air escaping under the lower lateral band.

OV-10 ---------------OV-10 designed specifically for counter-insurgency and limited war operations. Capable of speeds in excess of 245 knots; range 1200 miles; ceiling 28,000 feet.

PARACHUTE -----------An umbrella-like device designed to trap a large volume of air in order to slow the descent of a falling load attached to a parachute.

PACK (PACK ASSEMBLY) The term usually denotes the container alone. When so used,it is defined as a container that encloses the canopy or deployment bag and provides for a means of opening to allow deployment of the canopy. The canopy may or may not be placed in a deployment bag or sleeve.

PARACHUTE, AIR-DROP -A parachute designed to deliver equipment and supplies from an aircraft in flight. It is used synonymously with the term cargo parachute.

PARACHUTE ASSEMBLY --An assembly consisting of canopy, risers, or bridles, deployment bag, and in some cases, a pilot chute. The pack harness and reserve parachute are all part of the assembly.

PARACHUTE, ATTACHED-TYPE --A parachute, the pack of which is so attached to an aircraft or other carrier that the canopy deploys from the pack as the load falls away.

PARACHUTE, BACK-TYPE --A parachute designed to be worn on the wearer's back and shoulders.

PARACHUTE, CHEST-TYPE --A parachute designed to be attached to the wearer's chest.

PARACHUTE, EXTRACTION --A parachute used to extract cargo from aircraft in flight, and to deploy cargo parachutes.

PARACHUTE, FREE FALL --A parachute not attached to the aircraft that is activated by the jumper.

PARACHUTE PACK ------Such as back pack or chest pack means the parachute assembly less the harness. That is, it means the container, canopy, suspension lines, pilot chute, users and connector links.

PARACHUTE, PERSONNEL --A parachute used by human beings.

PARACHUTE, STATIC LINE OPERATED -- A parachute operated by a length of webbing after a jumper has fallen the length of the static line. The ripcord pins are pulled from the pack, the parachute opens, and a break tie breaks, freeing the parachutist.

PARACHUTE, STATIC LINE TYPE -- A parachute that is activated by a static line attached to an anchor line, cable or ring inside the aircraft.

PARACHUTE RESERVE ---A second parachute worn on the chest and used in the event of a malfunction of the main parachute.

PARACHUTE, TROOP ----A parachute used primarily by paratroopers for a premeditated jump over a designated area.

PC -----------------Para-Commander.

PERMEABILITY --------The mass rate of flow or the volume rate of flow per unit projected area of cloth for a prescribed pressure differential.

PILOT CHUTE ---------A small parachute used to aid and accelerate main-canopy deployment. Some types of pilot chutes are equipped with a spring-operated, quick-opening device. The frame is so compressed that it will open immediately when it is released from the pack.

RATE OF DESCENT -----The vertical velocity, in feet per second (FPS) of a fully opened parachute. The rate of descent of a parachute is governed by the design and the area of the canopy,

the permeability of the canopy fabric, the weight of the load, and the density of the air through which it is descending.

RELIABILITY ---------Reliability is inversely related to the expected rate of failure; it can be measured by subtracting the expected probabiltiy from unity.

RIPCORD -------------A device that consists of a cable, locking pins, and a grip which activates the parachute when pulled or released.

SA-7 ----------------The Soviet (USSR) SA-7/9 surface-to-air missile systems are designed specifically for low altitude interceptions and has an active homing system and the speculation that the other might be intended to fill the gap/range/altitude between Gainfill and Ganef.

SAIL ----------------A term used to designate a condition noted in the deployment of a parachute canopy when the canopy, just after leaving its pack but still attached to a static line, is exposed broadside to the airstream and temporarily assumes a shape similar to a sail.

SEAL ----------------Sea Air Land.

SKIRT ---------------The reinforced hem forming the periphery of a canopy.

SLEEVE --------------A tapered, fabric tube in which the canopy is placed to control deployment.

SNATCH FORCE --------The shock produced on the load when the parachute assembly fully strings out and becomes suddenly accelerated to the same speed as the load. Comes prior to opening shock.

SPECIFIC GRAVITY ----The ratio of any volume of a substance to the weight of an equal volume of another substance.

SPORT PARACHUTING ---The making of premeditated parachute jumps for pleasure.

STATIC LINE ---------A line attached to the aircraft and to the parachute which initiates deployment of the parachute as the load falls away from the aircraft.

STRENGTH, TENSILE ---The tension, measured in pounds, required to break a material. The tensile strength of a fabric is stated in pounds per inch width for wrap and for filling. The tensile strength of webbing and tapes is stated for the full width, such as 250-lb. tape.

STOW ----------------Any one loop of static line or suspension line compactly secured to the parachute pack.

TERMINAL VELOCITY ---The equilibrium velocity which a free falling body can attain against the resistance of the air. The greatest speed at which a human body falls through the atmosphere (14.7 psi). Resistance of the air overcoming the pull of gravity establishes the approximate figure of 176 FPS or 120 MPH.

TEST DROP -----------A test to determine the working efficiency of a parachute and its system by releasing it from an aircraft or from some height above the ground under conditions very similar to those found, or anticipated to be encountered in a normal operation.

TM ------------------Technical Manual.

TN ------------------Technical Note.

U1B -----------------The U1B is a Bell helicopter capable of speeds in excess of 150 knots; carries six passengers; cruises at 138 knots; and has a normal range of 286 miles.

UH1M ----------------A single-rotor general purpose helicopter. The fuselage is conventional all-metal semi-monocoque structure powered by one 1400 SHP Lycoming T 53-L-13 turboshaft mounted aft of the transmission with cabin space of 220 cubic feet. This helicopter can carry 11-14 troops.

ULTIMATE LOAD -------Maximum load that can be applied without causing any part of the structure to fail.

VELOCITY ------------A vector quantity that includes both magnitude (speed) and direction relation to a given frame of reference; also the time relation of change of position.

VELOCITY, EQUILIBRIUM --The velocity a free falling body can attain when the drag is equal to the weight, i.e., the acceleration equals zero. Terminal velocity.

BIBLIOGRAPHY

1. FLEET MARINE FORCE MANUAL 2-2, "AMPHIBIOUS RECONNAISSANCE," Department of the Navy, Headquarters Marine Corps, United States Marine Corps, Washington, D. C. , May 1976.

2. FIELD MANUAL, FM 31-19 (Test), "TECHNICAL TRAINING OF MILITARY FREE FALL PARACHUTISTS," Headquarters, Department of the Army, p. 2-1, July 1974.

3. "DEVELOPMENT TEST 11 (SVC) OF MFF PARACHUTE SYSTEMS," U. S. Army Airborne Communications and Electronics Board, Fort Bragg, North Carolina, 20 Feb 1975.

4. U. S. Naval Aerospace Recovery Facility Technical Report 8-66, "PERFORMANCE EVALUATION MC1-1," by G. L. C. Menard, April 1967.

5. "PERFORMANCE OF AND DESIGN CRITERIA FOR DEPLOYABLE AERODYNAMIC DECELERATORS," American Power Jet Company, Ridgefield, New Jersey, December 1973.

6. "EVALUATION OF MILITARY FREE FALL PARACHUTE SYSTEMS," DT, II, TECOM Project numbers 8-EG-065-000-010/011, January 1975.

7. "STEERABLE PARACHUTES," Project Number 20-69-10, Major James Steele, U. S. Marine Corps, Research, Development, Test, and Education, Development Center, Quantico, Virginia, January 1975.

8. "ECONOMIC ANALYSIS HANDBOOK," 2nd edition.

9. Department of Defense Instruction, 7041.3, "ECONOMIC ANALYSIS OF PROPOSED DOD INVESTMENTS, 18 October 1972.

10. "WORLD CHAMPIONSHIP PARACHUTES," L. Kalabukhova, FSTC-HT-23-1511-73, DA Task No. T70-23-01, AD 786 838, January 1974.

11. Swartz, T. J., Major, United States Marine Corps, Marine Liaison Officer, Operations Staff, Test Center, Fort Bragg, North Carolina telephone communications with author on 18 June 1976.

12. Department of the Army Technical Bulletin TB 43-0002-4, "MAINTENANCE EXPENDITURE LIMITS FOR FSC GROUP 16," 30 May 1975.

13. U. S. Army Quartermaster School, "QUARTERLY AIRDROP REVIEW AND MALFUNCTION ANALYSIS," Volume IV, Oct-Dec 1974, p. 3-4, and Volume I, Jan-Mar 1976, p. 8-16.

14. "THE FINDINGS OF THE USPA MALFUNCTION PROJECT," Truffer, J., Parachutist Magazine, Vol. 1 '76, p. 5-16, January 1976.

15. Neil, R. D., Test and Evaluation Division, United States Army Aviation System Command, St. Louis, Missouri telephone conversation with the author on 18 June 1976.

16. Table of Organization (T/O) 4623M, dated 14 June 1975 for Force Reconnaissance, Fleet Marine Force, United States Marine Corps.

17. Hambrick, Frank W., Master Gunnery Sergeant, United States Marine Corps, LoftNCO, 2nd Air Delivery Platoon, Beach and Port Operations Company, Headquarters and Service Battalion, Force Troops/2d Force Service Support Group, Fleet Marine Force Atlantic, Camp Lejeunce, North Carolina telephone conversation with the author on 23 May 1976.

18. U. S. Naval Aerospace Recovery Facility, El Centro, California, Letter END-1/6/FP over 694.23, serial 832, dated 29 August 1972.

19. Goodmanson, John J., Major, United States Army, Training Officer, U. S. Army Quartermaster School, Fort Lee, Virginia telephone conversation of 21 June 1976.

20. Capers, James Jr., Captain, United States Marine Corps, Commanding Officer, 2d Force Reconnaissance Company, Force Troops/2d Force Service Support Group, Fleet Marine Force Atlantic, Camp Lejeune, North Carolina telephone conversation with the author on 13 September 1976.

21. Technical Manual (TM) 57-220, "TECHNICAL TRAINING OF PARACHUTISTS," Headquarters, United States Army June 1968.

22. "WORLD CHAMPIONSHIP PARACHUTES," Kalaberkhova, L., FSTC-HT-23-1511-73, DIA Task Number T-70-23-01, AD 786 838, January 1974, p. 7.

23. U. S. Naval Aerospace Recovery Facility Technical Note TN 1005-70, "PERFORMANCE EVALUATION TESTS FOR SAILWING," by Menard, G. L. C., April 1967.

24. U. S. Naval Aerospace Recovery Facility Technical Note TN 100-70, "PERFORMANCE EVALUATION TESTS FOR SLOTTED PARA-WING," by Menard, G. L. C., June 1970.

25. U. S. Naval Aerospace Recovery Facility Technical Note TN 1009-70, "PERFORMANCE EVALUATION TESTS TWIN CATENARY REEL PARA-WING," by Menard, G. L. C., June 1970.

26. U. S. Naval Aerospace Recovery Facility Technical Note TN 2-69, "PERFORMANCE EVALUATION TESTS PARA-FOIL," by Menard, G. L. C., September 1969.

27. U. S. Naval Aerospace Recovery Facility Technical Report 9-74, "PERSONNEL PARACHUTE 28' FLAT," by Menard, G. L. C., December 1974.

28. U. S. Naval Aerospace Recovery Facility Technical Report 1006-70, "PERFORMANCE EVALUATION TEST VOLPLANE," by Menard, G. L. C., June 1970.

29. U. S. Naval Aerospace Recovery Facility Technical Report 5-71, "PERFORMANCE INVESTIGATION OF MANEUVERABLE PARACHUTES," by Menard, G. L. C., February 1972.

30. Department of the Army Technical Manual, TM 10-1670-205-13, "OPERATOR ORGANIZATIONAL AND DS MAINTENANCE MANUAL, PARACHUTE BACK (HALO)," December 1967.

31. Department of the Army Technical Manual, TM 10-1670-213-23, "ORGANIZATIONAL AND DS MAINTENANCE MANUAL FOR 35-FOOT DIAMETER PARACHUTES," April 1969.

32. U. S. Naval Aerospace Recovery Facility Technical Report 8-66, "PERFORMANCE EVALUATION 35-FOOT DIAMETER EXTENDED SKIRT MANEUVERABLE PERSONNEL PARACHUTE CANOPY ASSEMBLY WITH "TU" ORFICE," by Menard, G. L. C., April 1967.

33. U. S. Naval Aerospace Recovery Facility Technical Report 8-67, "PERFORMANCE EVALUATION TESTS OF 20 AND 24 FOOT PARAWINGS," by Menard, G. L. C., November 1968.

34. U. S. Naval Aerospace Recovery Facility Technical Report 9-74, "PERSONNEL PARACHUTE FOUR-LINE RELEASE SYSTEM PERFORMANCE INVESTIGATION OF APPLICATION TO 28-FOOT DIAMETER FLAT CIRCULAR PARACHUTE," by Menard, G. L. C., December 1974.

35. Technical Report TR-71-32-OSD, "A GENERAL THEORY OF PARACHUTE OPENING," by Ross, Edward W., Jr., Office of the Scientific Director, U. S. Army Natick Laboratories, Natick Massachusetts, January 1971.

36. USATECOM PROJECT NO. 8-CO-26A-000-001, "SERVICE TEST OF CERTIFICATION AND PROCEDURES FOR REAR MOUNTED RUCKSACKS IN HALO JUMPS," by Francis, Brett A., U. S. Army Airborne Electronics and Special Warfare Board, Fort Bragg, North Carolina, April 1970.

37. USAAVLABS TECHNICAL REPORT 66-82, "INVESTIGATION OF DEPLOYMENT AND LANDING LOADS WITH A LIMP PARAGLIDER," by Sebczak, John W., U. S. Army Aviation Materials Laboratories, Fort Eustis, Virginia, September 1966.

38. Technical Report AFFDL-TR-71-37, "PARA-FOIL STEERABLE PARACHUTE, EXPLORATORY DEVELOPMENT FOR AIRDROP SYSTEM APPLICATION," by Speelman, R. J. III, et al, Air Force Dynamics Laboratory, Air Force Systems Command, Wright Patterson Air Force Base, Ohio, April 1972.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3.	Chairman, Code 54 Department of Administrative Sciences Naval Postgraduate School Monterey, California 93940	1
4.	Commander C. P. Gibfried, Code 52Gf Department of Computer Science Naval Postgraduate School Monterey, California 93940	1
5.	Commander A. C. Crosby, Code 54Cw Department of Administrative Sciences Naval Postgraduate School Monterey, California 93940	1
6.	Major Robert J. McLaughlin, USMC 308 Forest Grove Avenue Jacksonville, North Carolina 28540	1
7.	Commandant of the Marine Corps, Code OTTI Headquarters, United States Marine Corps Washington, D. C. 28380	1
8.	Commanding Officer 2d Force Reconnaissance Company Force Troops/2d Force Service Support Group Fleet Marine Force Atlantic Camp Lejeune, North Carolina 28542	1

Thesis
M2425 McLaughlin
c.1
170351
An analysis of personnel parachutes for use by Marine Corps Force reconnaissance units.